

**ENHANCING THE CONSTRUCTION RESILIENCE
TO COPE WITH THE POST COVID-19
PRECAUTIONS MEASURES UNCERTAINTY:
A FUZZY-BASED APPROACH**

BY

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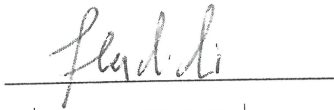
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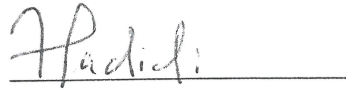
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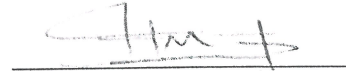
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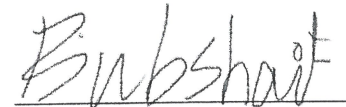
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DEDICATION

I thank God Almighty first and foremost for the great grace that he has bestowed upon me, then I thank those who favored them. My beloved parents do not cease to me for all their efforts from the moment of my birth to these blessed moments.

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LIST OF ABBREVIATIONS

COVID-19	Coronavirus disease
FCM	Fuzzy Canonical Model
FGDMA	Fuzzy Group Decision-Making Method
FUCOM	Full Consistency Method
BWM	Best Worst Method
AHP	Analytic Hierarchy Process
DFC	Deviation Value of The Obtained Weight
FTN	Fuzzy Triangular Number
FDM	Fuzzy Decision Matrix
RL	Risk Likelihood
C	Consequence
PP	Professional Position
EP	Job Experience
EO	Experience Working On Previous Projects
AQ	Academic Qualifications
Wind	Weight of Professional Competence
Wg	Global Weight
CPT	Conditional Probability Tables
CPR	Construction Project Resilience

ABSTRACT

Full Name : Omar Abdulla Alhaj Ebrahim
Thesis Title : ENHANCING THE CONSTRUCTION RESILIENCE TO COPE WITH
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This thesis proposes a fuzzy-based improvement model for evaluating the ability of construction projects to withstand the emergence of COVID-19 outbreak. The work starts by finding the risks on the construction project resulting from the application of precautionary measures which usually lead to major cost overrun or schedule delays. Then, a fuzzy multi-criterion framework is built and combined with a fuzzy simulation model (FCM) to assess the impact of each of the project uncertainty factors resulting from the COVID-19 measures. The model output is a probabilistic COVID-19 risk assessment offers better predictions by taking into consideration domain experts' evaluations and subjectivity, as well as the uncertainty involved with choices made during the decision-making process. The outcomes report shows that there are 16 major factors that affecting the construction projects, the delays of importing the materials duration shows the highest impact on the projects. Then the results we validated by the Axioms-testing-based method and then by testing the model on finished project and comparing the project standing with model results.

Risk management in construction projects is an essential task for the success of construction projects. The research presents a second model to utilize the most critical risk factors defined in the first model to predict the success assessment for a projects' portfolio. The project manager defines the projects with the highest success rate to be prioritized in devoting resources and efforts after the pandemic. The full consistency method is used to predict the project's success rate. In

order to validate the developed system, five projects were studied. The project success rate found by the second model was compared with the projects managers assessment for the identified case studies. In the first case, the ability to withstand disasters for three hospitals under construction was compared and measured. It showed that the hospital located in the city of Dammam has a better level of resistance to collapse, as the percentage of impacts on the project did not exceed 44%. On the other hand, in the second case, the level of collapse resistance was measured for two commercial projects under construction, and the results showed that the commercial tower project located in the city of Dammam has a better durability than the commercial complex project located in the city of Al-Khobar, and this reflects the situation in which the projects were at the time of doing this scientific research.

The second model can help contractors to assess the extent to which existing projects are resilient to disasters and to achieve the lowest possible loss ratio taking into account (1) the resources available to the contractor in the local and international market, (2) the precautions imposed on the sites during and outside working hours, (3) the productivity and quality of the workforce, and (4) the direct and indirect costs of the project.

ملخص الرسالة

الاسم الكامل: عمر عبد الله الحاج ابراهيم

عنوان الرسالة: تعزيز مرونة المشاريع الانشائية للتكيف مع المخاطر الناتجة من تطبيق الاحترازاات الوقائية للحد من انتشار فايروس كوفيد 19.

التخصص: الهندسة المعمارية وإدارة الإنشاءات

تاريخ الدرجة العلمية: شوال 1444

إدارة المخاطر في المشاريع الانشائية تعتبر احدى المهام الأساسية لنجاح مشاريع البناء (مثل إنشاءات المدارس والمستشفيات والمباني التجارية وما إلى ذلك) التي تنطوي على استخدام الكثير من الموارد. ترتبط الموارد بتكاليف عالية تؤثر بشكل كبير على الميزانية الإجمالية للمشروع. لذلك ، فإن القدرة على العثور على الترتيب الأمثل للمشاريع من حيث مدى صموده في وجه الكوارث الذي ينتج عنه أقل خسائر في التكلفة أو في الجدول الزمني والذي بدوره سيساعد المقاولين في تسليم هذه المشاريع بأقل خسائر بالميزانية و أقل تأخير في الجدول الزمني المخطط. تم تطوير العديد من نماذج التحسين الرياضية والمحاكاة لتحسين عمليات مقاومة وتقادي المخاطر. ومع ذلك، فإن معظم أنظمة التحسين هذه لم تأخذ في الاعتبار المخاطر الناتجة من تطبيق الإجراءات الاحترازية لتفشي فايروس كورونا وما مدى تأثيرها في سير المشاريع الانشائية.

تقدم هذه الرسالة نموذجًا للتحسين القائم على المحاكاة لعمليات تقييم مدى قدرة المشاريع الانشائية للصمود في ظل ظهور الكوارث من خلال إيجاد التقييم الأمثل للمخاطر الناتجة من تطبيق الإجراءات الاحترازية للحد من انتشار فايروس كوفيد 19 في الشرق الأوسط والذي ينتج عنه أقل خسائر في التكلفة و / أو الحد من التأخير في الجدول الزمني. يدمج النظام المقدم في القسم الثالث نموذجًا مضطربًا متعدد المعايير مع نموذج محاكاة مضطرب FCM الذي بدوره سيقوم بتقييم ما مدى قوة تأثير كل عامل من العوامل السلبية الناتجة من انتشار فايروس كوفيد 19 وقياس مدى قوة التأثير البيئية بين كل عامل والآخر والذي يؤدي بالمشروع الى تجاوز التكلفة المخصصة للمشروع حيث يصبح انجاز المشروع امر شبه مستحيل. اهم الخرجات من النموذج تتمثل في ترتيب و مدى تأثير المخاطر المؤثرة على المشاريع الانشائية والتي ظهرت نتيجة لتطبيق الإجراءات الاحترازية للحد من تفشي فايروس كوفيد 19. هذه المخرجات ستكون بمثابة مدخلات للنظام في القسم الرابع الذي سيساعد في تطوير نموذج لتقييم آثار التدابير الاحترازية لفايروس كوفيد 19 على مستوى عدم اليقين في مرونة المشاريع الانشائية. من أجل التحقق من صحة النظام المطور ، تم حل خمس مشاريع. بمقارنة النتائج التي تم الحصول عليها بنموذجنا والنماذج للحالات المختارة ، كانت نتائج تنبؤ مدى قوة مقاومة المشاريع للصمود في وجه الكوارث واقعية وتعكس الحالة الراهنة للمشروع. في الحالة الاولى تم مقارنة وقياس مدى

قدرة الصمود في وجه الكوارث لثلاث مستشفيات تحت اعمال التشييد. وظهرت ان المستشفى الواقع في مدينة الدمام ليه مستوى أفضل في مقاومة الانهيار حيث ان نسبة التأثيرات على المشروع لم تتجاوز 44.1%. وفي المقابل في الحالة الثانية تم قياس مستوى مقاومة الانهيار لمشروعين تجاريين تحت الانشاء وظهرت النتائج ان مشروع البرج التجاري الواقع في مدينة الدمام لديه قوة تحمل أفضل من مشروع المجمع التجاري الواقع في مدينة الخبر وهذا يعكس الحال التي كانت عليه المشاريع في وقت عمل هذا البحث العلمي.

يمكن أن يساعد النموذج الذي تم إنشاؤه المقاولين في تقييم مدى قابلية المشاريع القائمة على الصمود في وجه الكوارث وتحقيق أقل نسبة خسارة ممكنة مع مراعاة (1) الموارد المتاحة للمقاول في السوق المحلية والدولية، (2) الاحترازاات المفروضة على المواقع في أوقات العمل وخارجه، (3) إنتاجية وجودة القوى العاملة ، (4) التكاليف المباشرة وغير المباشرة للمشروع.

CHAPTER 1 INTRODUCTION

The construction industry is the most finance, vital, and sensitive sector for economic growth and activities, particularly in developing countries [1]. The spread of COVID-19 pandemic put almost all industries sectors including construction around the world in cost overrun and schedule delay. The COVID-19 pandemic has had a severe effect on construction sector's operations and has been amongst the hardest strike. Occupational risks for COVID-19 infection. Many projects were suspended, thousands of people lost their jobs, and some of the largest companies declared bankruptcy or an inability to complete their projects [1,2].

The number of pandemic deaths forced world governments to severely reduce all economic and social activities, resulting in complete paralysis of construction projects. This stoppage was suddenly imposed and lacked any substitute construction methods that might have helped project managers continue their projects as planned or at least meet a portion of the targeted productivity levels [3]. What made matters worse is that governments had to implement precaution measures to limit the spread of COVID-19, which had major impact on the progress of construction activities. The severity and strictness of precaution measures varies from country to another. In Saudi Arabia, 2018, around 3.5 million people were involved in construction activities with a total value of projects exceeding 160 million dollars [4].

Researchers have explored potential solutions for the construction industry to help who's involved in construction industry to cope with the pandemic's effect and avoid such situations in the future. However, the scarce research on this topic has yielded only limited post-pandemic solutions to help decision-makers in construction industry. This study explores the impact of implementing imposed COVID-19 precaution measures effect on the construction industry from two aspects.

First, in order to initiate a probabilistic risk assessment that offers better predictions of the projects uncertainty by taking into consideration domain experts' evaluations, subjectivity and the uncertainty involved with choices made during the decision-making process. First, a fuzzy canonical model (FCM) has been developed to identify potential critical pandemic-related factors and predict their severity on construction projects cost overrun and schedule delay. Second, the study develops a risk-based model to utilize the most critical risk factors identified in the first model to predict the success assessment of project portfolio. This can be used to reflect a construction project's responsiveness to external disruptions while returning to its initial state.

1.1 Research Significance

Avoiding project schedule delays and cost overruns in construction projects has become a worldwide challenge in the COVID-19 era. Existing assessment methods and models have limitations with regards to assessing the impact COVID-19 on construction projects, especially the probabilistic causal correlations among COVID-19 risks.

A probabilistic COVID-19 risk assessment offers better predictions by taking into consideration domain experts' evaluations and subjectivity, as well as the uncertainty involved with choices made during the decision-making process.

The risk-based model will help contractors to assess the extent to which existing projects are resilient to disasters and to achieve the lowest possible loss ratio considering resources availability, precautions imposed, and the direct and indirect costs of the project.

1.2 Research Objectives

This study targeted the following research objectives:

1. Develop a knowledge-based expert system for assessing construction project cost overruns resulting from COVID-19 precaution measures (chapter 3: A FUZZY CANONICAL MODEL FOR INVESTIGATING THE IMPACTS OF COVID-19 PRECAUTION MEASURES ON CONSTRUCTION PROJECTS).
2. Predict the probability of cost overruns for a construction project using the FCM to assist early risk management planning, resulting in better control over the project (chapter 3: A FUZZY CANONICAL MODEL FOR INVESTIGATING THE IMPACTS OF COVID-19 PRECAUTION MEASURES ON CONSTRUCTION PROJECTS).
3. Develop a model for evaluating the impacts of COVID-19 precaution measures on a construction project's resilience uncertainty level (chapter 4: ASSESSING CONSTRUCTION RESILIENCE IN RESPONSE TO COVID-19 PRECAUTIONS MEASURES).

1.3 Research Structure

The research is divided into four chapters. Chapter 1 provides an overview of the study topic, its importance, and the expected outputs. Chapter 2 illustrates the research methodologies followed to achieve the three objectives. Chapter 3 is a self-contained exploration of research objectives 1 and 2. Chapter 4 is a self-contained analysis of research objective 3. Chapter 5 draws concluding summary from the two research outputs presented in Chapters 3 and 4 and describes the research findings, practical implications and directions for future work.

CHAPTER 2

RESEARCH METHODOLOGY

This chapter is dedicated to highlight the research methodologies followed to achieve the highlighted objectives of chapters 3 and 4.

2.1 Method 1: Fuzzy Canonical Model (FCM)

Fuzzy canonical model (FCM) combines fuzzy group decision-making method (FGDMA) and canonical model. FCM is a modified Bayesian belief network model which addresses uncertainty of the opinions of domain experts.

The existing risk assessment models have limitations when it comes to dealing with complex problems, incorporating the probability of the causal relationship of risks and probabilistic data of risk assessment, and accounting for the subjectivity and uncertainty of the opinions of domain experts who make decisions. The above limitations have been addressed by the FCM as follows:

- Reduces computational load and effort required for model development.
- The subjectivity and uncertainty in domain experts' assessments, and
- The time required for the domain experts to elicit probabilities that depend on certain conditions for the hazards present in complicated risk networks.

By resolving the key restrictions related to such models, FCM enhances the applicability of fuzzy-Bayesian models for cost overrun risks assessment in a complex and unpredictable project context. The model demonstrates and evaluates the cost overrun risk probability of construction projects, confirming its capability to highlight the most significant risks involved during the implementation

of the COVID-19 precautionary measures, such as reducing working hours, social isolation, a 14-day quarantine for infected workers, and related materials procurement issues.

2.2 Method 2: Full Consistency Method (FUCOM)

After the result of the model 1 came out with weighted ranking of the most significant risks associated with implementing the COVID-19 precaution measures, this section provides an indicator tool for evaluating the construction resilience level with the post COVID-19 precautions measures.

The selection of the most acceptable solution from a group of alternatives offered on the basis of the established criteria is what distinguishes difficulties in multi-criteria decision-making. The Full Consistency Method (FUCOM) is one of the new approaches for establishing the weights of factors in multi-criteria decision-making subjectively. In other words, The FUCOM is a tool that assists managers with handling their own subjectivity when prioritizing criteria using a straightforward algorithm and a scale that works for them. This approach allows for the accurate computation of the weight coefficient values for all items that are being compared to one another at a certain level of the hierarchy while also meeting the requirements of comparison consistency.

The following are some benefits that influence the decision maker to use the FUCOM:

- With the aid of FUCOM, the ideal weight coefficient values can be calculated using a straightforward mathematical method, permit the favoring of particular criteria when assessing phenomena in accordance with the demands of decision-makers at the time and reducing the risks associated with decision-making.

- Also, with the least amount of subjective sway and inconsistent expert opinions having the least amount of an impact based on final values of the criteria's weights, FUCOM offers the best weight coefficient values.
- The concept is adaptable and appropriate for use with various measuring scales that represent professional preferences.

Contrarily, the pairwise comparison's redundancy is present in the two models for evaluating the weights of criteria (the BWM and AHP models), making them less susceptible to subjective judgment mistakes. This issue is solved by the FUCOM methodological technique. By computing the error value for the generated weight vectors by finding DFC, FUCOM offers the capability to validate the model.

CHAPTER 3

A FUZZY CANONICAL MODEL FOR INVESTIGATING THE IMPACTS OF COVID-19 PRECAUTION MEASURES ON CONSTRUCTION PROJECTS

The fuzzy canonical model (FCM) combines the fuzzy group decision-making (FGDMA) method with the canonical model (modified Bayesian belief network model). The FCM significantly reduces the number of development and testing tasks, minimizing the model's computation complexity, domain experts' time and effort, and the subjectivity and ambiguity that accompany domain experts' decisions. In this research, FCM will be used to assess and evaluate the impact of COVID-19 precaution measures on schedule delay/cost overrun of construction projects.

Most project managers neglected to take any proactive actions in response to COVID-19 pandemic, even though the government's lockdown was anticipated before being implemented. Although it would have been impossible to avoid the lockdown's effects, proper risk assessment would have contributed to better loss control once precautionary measures were imposed. Thus, this study sought to answer the following two questions. What were the most potent effects of imposed COVID-19 precaution measures on construction projects during the execution phase?

and what are the most recommended expert methods/strategies for minimizing the probability of schedule delays/cost overruns, considering the factors outlined below?

- o Ongoing projects located in the Middle East in the construction phase
- o After the emergence of the COVID-19 pandemic
- o After implementation of the government's COVID-19 precaution measures

The study investigated the impact of COVID-19 precaution measures on the construction industry by developing a fuzzy logic-based model. First, the risks associated with COVID-19 precaution measures will be identified from the literature and filtered by interviews with subject matter experts. Second, the factors network is established to illustrate the relationship between factors that will lead the construction projects to schedule delays/cost overruns. Initially, Saudi Arabia imposed a complete lockdown for 21 days at the start of the pandemic in 2019. As a result, construction companies incurred heavy losses from the imposed precautionary measures. As such, construction companies had to abide by post-COVID-19 precautionary measures that required companies to:

- Reduce working hours and the number of employees allowed to be present at the same time and in the same place, thus extending the time duration for project activities.
- Work remotely which resulting in less productivity.
- Maintain the continuous sterilization of employee locations.
- Impose facemask rules for everyone which affected labor productivity since facial masks are difficult especially for workers operating in hot weather.

Consequently, the construction sector suffered severely. Many projects were suspended, thousands of people lost their jobs, and some of the largest companies declared bankruptcy or an inability to complete projects. The COVID-19 precaution measures prevented construction companies from working at their full capacity which drastically reduced their productivity levels [5].

Therefore, studying the strategies of construction project decision-makers in response to COVID-19 precaution measures is essential for enhancing project resilience to withstand future disasters. A case study was used to demonstrate and test the applicability of the proposed FCM and illustrate

the most serious threats of the post-COVID-19 context. The primary objective of this study is to provide an analysis of the major impacts of experts' recommendations related to COVID-19 on projects in the construction stage. The model illustrated all COVID-19 impacts affecting projects in the construction stage, excluding projects in design, bidding, or procurement phases, creating a potential opportunity for further research to develop enhanced studies on the design and materials procurement phases.

3.1 Literature Review

The following subsections describe the most recent literature addressing: (a) the impact of COVID-19 on project finance (b) project scheduling and performance, and (c) the most recent fuzzy-based models.

3.1.1 Impacts of COVID-19 on project finance

Some of the major financial impacts on construction projects resulting from COVID-19 include new health precautions for labor accommodation and mobilization, rising raw materials prices, soaring project costs and insurance premiums, and new difficulties with cost budgeting and project tendering.

3.1.1.1 Health precautions measures for labor accommodation and mobilization

Pandemics such as COVID-19 have significant consequences for human rights and physical and mental health. According to the World Health Organization's COVID-19 status dashboard, in 2020, the virus spread to 216 nations, infected over 28,800,000 individuals globally, and killed over 900,000 people worldwide [6]. The imposed health precautions measures for labor accommodation and mobilization in Saudi Arabia led to an increase in overall worker

accommodation costs. The main restrictions affecting labor-related expenses in Saudi Arabia included [7,8]:

- o Limiting labor capacity housing to a separate room for each worker or a minimum of 4 square meters had to be allocated to each worker, excluding other facilities. Companies were forced to increase the number of housing facilities to reduce labor condensation in housing units which caused an additional burden on the project's budget.
- o Companies were obligated to provide meals for workers with utensils intended for one-time use, and workers were prohibited from cooking in the house which increased expenses.
- o A sanitary isolation room had to be prepared for workers infected by COVID-19.

3.1.1.2 Rising raw materials prices

The imposed precautions led to a sharp increase in materials cost. It is reported that material costs inflated from 1.8% to 3.1% in Saudi Arabia [9]. The Saudi National Iron Industry Committee stated that iron prices witnessed a sharp increase, the largest since 2011, due to the sudden shift from importing goods and raw materials from China. This shift coincided with a collapse accident at one of the largest iron export mines in Brazil in 2020 which reduced iron exports by 30% [10,11].

3.1.1.3 Project cost and soaring insurance premiums

Indirect costs are closely related to a project's duration; the more time a project takes to finish, the more indirect costs will be incurred. Ideally, indirect costs represent between 8% and 12% of the total cost of a project [12]. However, indirect costs increased for most projects due to COVID-19 pandemic. Few projects took advantage of the situation and reduced indirect costs by introducing

solutions to enhance the performance of the project delivery [12]. In some projects human resource accommodations were moved from the city to the project site. Even though this practice incurred mobilization costs and workers accommodation costs, it eventually reduced indirect costs by improving the production rate and reducing the delivery time [13].

3.1.1.4 Additional budgeting conditions for project tendering and estimation

The pandemic's effect can be categorized under force majeure, which can only be estimated based on experienced judgment. The COVID-19 pandemic risk was not included in the budget of any project awarded in 2020 or early 2021. This eventually caused a budget shock that made many small contractors decline or withdraw from projects, or even lose the ability to complete their projects which led to declare bankruptcy. Some projects in Saudi Arabia were shutdown or temporarily halted for an unknown period because of inaccurate budget and bid estimation [14].

3.1.2 Impacts Of COVID-19 on project performance

Project scheduling was negatively affected by COVID-19 imposed precaution measures due to issues related to delays in materials purchase and delivery, lockdown and working hours restrictions, and probability of project cancelation or postponement.

3.1.2.1 Materials purchase and delivery

Most companies supplying raw materials announced delays in the delivery of materials which resulted in project schedule delay. For example, a particular contractor submitted a request to import several building elements (e.g., curtain wall systems) from Germany. However, the complete closure of all activities in Germany due to the COVID-19 pandemic led to delay scheduled materials procurement for more than three months [15].

3.1.2.2 Project cancelations

The implementation of COVID-19 precaution measures led to a sudden cessation of construction activities which delayed deliverables submissions and made on-time completion impossible. As a result, 40% of human resources involved in construction lost their jobs due to project closure [16]. The alternative options and solutions for project owners, left them with no choice but to suspend construction operations and stop the project. Consequently, this resulted in financial losses for the owners and employees [16].

3.1.2.3 Lockdown and working hours restrictions

In the second quarter of 2020, the Middle East recorded the largest decline in the construction activity index by 40%, while the rest of the world registered an average of 25% decline in the construction activity index [17]. Recent statistics have shown that globally, 25% of construction projects are still on hold with approximately 140 days' extension [17].

Tables 3.1 summarizes the most important influential factors and their impact on construction projects. The identified factors provide the basis of a real-life study that will be conducted on several projects to measure how much COVID-19 impacted the construction industry.

Table 3.1 Main COVID-19 precaution measures impact on construction projects

CATEGORY	#	FACTOR	REFERENCES
COVID-19 Impacts on Company Accommodation/ Site Accommodation Units	1	Limit the labor allowed inside a housing unit	[18,19]
	2	Provide meals for workers and utensils intended for one-time use	[18–20]
	3	Prepare a sanitary isolation room for workers suspected of contracting COVID-19	[7,18–20]
	4	Inflation of site accommodation/company accommodation costs	[21,22]
COVID-19 Precautions Measures Impacts at the worksite	5	Workers delayed/relegated to outside the country due to border closures	[7,18,23,24]
	6	14-day quarantine period after infection	[16,17,19]
	7	Safety inspectors rarely visiting the site, resulting in a reduction in focus on general safety	[19,21]
	8	Low quality of work	[11,24,25]
	9	Miscoordination between parties and construction teams	[18,26,27]
	10	Increase in human resources and expert prices/wages	[25,28]
	11	Social distancing resulting in fewer workers allowed on site	[7,18,19,22,23,25,29]
	12	Shortage of human resources, technicians, and operators	[18,24,27,29–31]
	13	Reduced working hours	[7,9,17,22,32]
	14	Construction errors/mistakes	[22,23,25,31,33]
	15	Increase in the demand for expert workers	[11,19,21]
	16	Decline in worker productivity	[7,13,24,26,31,32,34–37]
	17	Safety measures and health protocols (masks, disinfectants, hand sanitizers)	[7,17–19,25,33,34,37]
	18	Lack of PPE causing a decrease in productivity	[25,33,34]
	19	Weakness in negotiation with subcontractors for intended work price	[25,38]
	20	Poor contractor performance	[21,26,39,40]
	21	Transition to work from home for onsite personnel	[40,41]

Table 3.1 Main COVID-19 precaution measures impact on construction projects (continue)

CATEGORY	#	FACTOR	REFERENCES
COVID-19 Impacts on Project Finance	22	Increased project expenses	[11,12]
	23	Site accommodations with limited capacity	[13,42]
	24	Owners cashflow/fund shortages	[5,37,43]
	25	Expenses associated with resuming a project after a period of inactivity	[9,16,21,44]
	26	Fluctuation in financial/governmental expenses	[25,37,39,40]
	27	Unable to proceed with required payment/unavailability of cash flow	[12,13,35]
	28	Poor risk assessment and budgeting	[14,21,26,27]
	29	Delays in worker salaries	[21,28,35]
	30	Increased project insurance costs	[24,27]
	31	Site accommodations required for distant construction projects	[13,42]
	32	Variations in market prices	[12,16,21]
COVID-19 Impacts on Materials and Suppliers	33	Unavailability of materials/equipment on the international market	[26,36]
	34	Inability to cover materials demand rates	[10,16]
	35	Factories shut down due to bankruptcy	[9,10,24]
	36	Transportation and working hour limitations	[7,38,45,46]
	37	Extended materials/equipment import duration	[24,29,30,46,47]
	38	Materials not complying with specifications/poor preparation	[11,15,25]
	39	Increased materials demand on the local market and availability shortages	[15,18,25]
	40	Materials delivery problems and delayed scheduled materials arrival times	[9,25,26,30]
	41	Increased equipment transportation and import costs	[9,10,25]
	42	Inflation/increase in raw materials/materials/equipment costs	[10,11,15,25,26,46]
	43	Reduction in equipment productivity caused by a lack of supervision	[25]

3.2 Risk Prioritization and Ranking Models Approaches

This section discusses the most recently used methods for assigning, prioritizing of criteria and alternatives, and their implications for project activities. For example, Basahel [45] integrated fuzzy AHP and fuzzy TOPSIS techniques to prioritize the elements that have a major impact on safety management system performance in construction projects. The hybrid fuzzy decision-making technique is used to evaluate safety management in construction industry [48].

Norouzi (2019) employed a hybrid fuzzy best-worst method (BWM) and fuzzy TOPSIS to evaluate and prioritize risk factors associated with the development of railway megaprojects in Iran [17]. Saeednamaghi (2021) used fuzzy TOPSIS to assess marketing mix alternatives. Linguistics in positive trapezoid fuzzy numbers were used to assign a weight to each alternative and determine a proximity coefficient for the rating of all alternatives from the fuzzy positive and negative ideal solutions [50]. Yucusan (2020) integrated fuzzy TOPSIS and BWM to evaluate and rank green suppliers. First, parameters for green motivation were identified based on the literature and conversations with subject-matter experts. Second, the weights for green supplier selection criteria were assigned using BWM algorithm [51]. Alkan and Kahraman (2021) used the q-rung orthopedic and fuzzy TOPSIS methods to evaluate government strategies against COVID-19 pandemic. The results showed that both methods suggested the same alternative with minor differences in rankings for the rest of the strategies [52].

Islam et al. (2019) developed a Fuzzy Canonical model (FCM) to assess the cost overrun risks in a complex and unpredictable project by addressing the key limitations of models used for predicting cost overrun probability for power plant projects. The research outcome proven that FCM overcomes the uncertainty and subjectivity involved in experts' decisions, reduces the

computational load, and dramatically reduces the time and effort needed to elicit the conditional probabilities of the risks involved in complicated risk networks [53].

3.3 Model Methodology and Definition of Input Data

First, the output factors identified in the literature review section related to the main effects of COVID-19 outbreak on construction projects were analyzed. Second, a structured expert-based questionnaire and comparative discussion were distributed to construction managers and engineers to discuss and verify the collected factors summarized in literature review Tables 3.1 which were collected from published research papers. The aims of the comparative discussion meeting are to remove irrelevant risks, add unrecognized risks, evaluate extent of risks presence in real life, evaluate their impact on construction projects, and establish an initial relationship network between dependent and independent risks. A full case study was conducted for several construction projects in Saudi Arabia at different construction stages. All were exposed to the pandemic and still in the recovery stage from the impacts. These steps provided supporting evidence regarding the effects of COVID-19, how industry experts responded to the pandemic's impacts, and what methods were adopted to complete the construction projects. A comparative discussion was then held to analyze all data inputs and derive the best solution for effectively reducing the losses resulting from COVID-19 precaution measures. The FCM method will enable decision-makers/construction managers to:

- Develop a clear vision for sorting the impactful factors in the Middle East that may lead to construction project scheduling delays/cost overruns.
- Efficiently develop backup arrangements for COVID-19 impacts and future signs which lead to least possible losses.

- Pursue optimum utilization of available finances, materials, equipment, and human resources.
- Prepare adequate and accurate project cost estimations for construction project bidding competitions.

3.3.1 Fuzzy Canonical Model Development

Figure 3.1 depicts a thorough flowchart of how the Fuzzy Canonical Model (FCM) was developed and used to assess the risks of COVID-19 precaution measures in construction projects cost overruns. To overcome drawbacks of fuzzy Bayesian risk assessment models, this study proposes an FCM model that integrates the canonical model with the FGDMA.

The canonical model evaluates the probability of dependent risk, while the FGDMA assesses the conditional probability or level of causation between risks as well as the prior probability of the independent risk (i.e., how much the effect of a parent risk is transferred to a dependent risk).

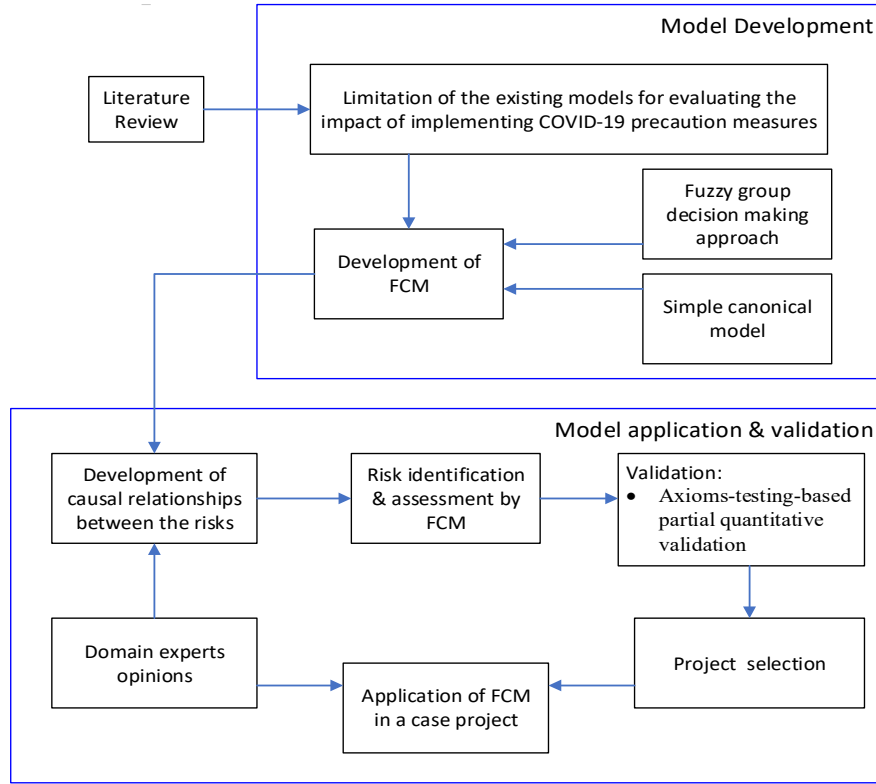


Figure 3.1 The development and application process of FCM

The FGDMA is an appropriate approach for an expert engaged in risk analysis for a complicated project subjected to uncertainty. This approach improves the reliability of decision-making by considering experts' judgement based on their professional competence and using a quantitative aggregation of experts' fuzzy judgments to assess individual risk [54]. Professional competence is assessed based on the attributes of the expert (i.e., position of authority, experience or involvement in construction/bidding, and academic qualifications), which shape the judgment value of their risk assessment. The FGDMA includes a quantitative technique for aggregating expert judgments to compute a risk score [55]. Thus, it does not have widely criticized constraints of conventional fuzzy if-then rules for decision-making that result from experts' widely differing levels of expertise, knowledge, and experience. FGDMA authorizes the elicitation of conditional probability parameters that are intuitive and thorough for subject matter experts, while also

reducing the computational load on the model [56]. However, the FCM has some limitations such as creating realistic causal risk networks, determining the likelihood that each risk will occur, and the financial impact on related dependent risks, determine how accurately this model can estimate risk. These are arbitrary, unpredictable, and exclusively based on the project-specific expertise and experience of domain experts. A methodical process for using the FCM to assess risks is described in the following subsections.

3.3.1.1 Fuzzy group decision-making approach

The suggested FGDMA evaluates the fuzziness of independent risk probabilities or establishes the degree of causation between risks causing cost overruns. Employing language concepts in risk assessment represents the ambiguity, imprecision, and uncertainty of subjective judgment. In this model, experts' judgments are provided by using phrases like "No Impact," "Very Low," "Low," "Medium," "High," "Very High," and "Extreme," which follow the numerical values of 0, 1, 2, 3, 4, 5, and 6, respectively, analyze the risk probability and evaluating their impact on project costs. Using the same language concepts, experts also assess the degree of causation between pairs of hazards. FGDMA uses the following formulae to assess the likelihood of risks, based on experts' assessments:

- The linguistic term's fuzzy triangular number (FTN) is derived as shown in Table 3.2 base on risk nature. The model can redefine or alter the FTN following user (or expert) knowledge and experience. The FTN can be adjusted to fit the risk assessment's time constraints, data accessibility, expected level of accuracy, and project risk assessment team preferences. However, as seen in previous research, the option to use alternative scales for FTN is frequently employed [57].

Table 3.2 Linguistic variables and corresponding fuzzy numbers

Grade of risk probability /consequence	Triangular Fuzzy number (FTN)	Defuzzified number range	Description
Extremely high	0.9, 1.0, 1.0	0.90 to 1.00	The risk event entails a massive cost overrun that is almost guaranteed to occur.
Very high	0.7, 0.9, 1.0	0.70 to <0.90	The risk event involves a very large cost overrun and has a very high probability of occurring.
High	0.5, 0.7, 0.9	0.50 to <0.70	The risk event has a high probability of occurring and has a large cost overrun.
Medium	0.3, 0.5, 0.7	0.30 to <0.50	The risk event entails a reasonably considerable cost overrun and is likely to occur.
Low	0.1, 0.3, 0.5	0.10 to <0.30	The risk event is extremely unlikely to occur and includes a small but considerable cost overrun.
Very low	0, 0.1, 0.3	0.025 to < 0.10	The risk event is extremely unlikely to occur and only entails a very little amount of major cost overrun.
None	0, 0, 0.1	0 to < 0.025	The danger event won't ever occur.

- Then, a fuzzy decision matrix (FDM) for each individual risk is created as shown in Eqn. 1:

$$(FDM_{RL/C}^r)_p = \begin{bmatrix} l_1 & m_1 & u_1 \\ \vdots & \ddots & \vdots \\ l_n & m_n & u_n \end{bmatrix} \quad (3.1)$$

where r represents a risk, RL represents the likelihood, C represents consequence of a single risk, p represents construction project phase, and n is the number of experts who have evaluated the risk, and l , m , and u represent the low, medium, and upper values, respectively.

- Risks weights are assigned according to the opinion of the experts for a given occurrence and, consequently, their dependability. The professional competence of specialists is determined by their professional position (PP), job experience (EP), experience working on previous projects (EO), and academic qualifications (AQ) [58]. Also, for the risk analysis to be more reliable, the level of professional expertise of each expert must be considered. The experts' weight of professional competence w_i^{lnd} is computed as follows [59,60]:

$$w_i^{lnd} = (w_{PP} + w_{EP} + w_{EO} + w_{AQ})_i \quad (3.2)$$

The global weight of an expert's professional competence w_i^g is defined by [61]:

$$w_i^g = \frac{w_i^{lnd}}{\sum_{i=1}^n w_i^{lnd}} ; \sum_{i=1}^n w_i^g = 1 \quad (3.3)$$

As indicated in Table 3.2, the maximum level of the fuzzy score is 1, and n denotes the number of domain experts who submitted their opinions for risk assessment. The global weights of all experts must add up to 1 to meet this requirement.

- The Fuzzy Decision Making (FDM) for a risk in a project phase p is converted to a weighted FDM by taking the expert's weight into account (WFDM), where:

$$(WFDM_{RL/C}^r)_p = (FDM_{RL/C}^r)_p = \begin{bmatrix} l_1 & m_1 & u_1 \\ \vdots & \ddots & \vdots \\ l_n & m_n & u_n \end{bmatrix} (X) \begin{bmatrix} w_1^g \\ \vdots \\ w_n^g \end{bmatrix} = \begin{bmatrix} l_1 w_1^g & m_1 w_1^g & u_1 w_1^g \\ \vdots & \ddots & \vdots \\ l_n w_n^g & m_n w_n^g & u_n w_n^g \end{bmatrix} \quad (3.4)$$

- The fuzzy arithmetic sum of the different columns of the above matrix is used to calculate the fuzzy score (FS) for a risk likelihood (RL) or risk consequence (C) in a project phase (p) as shown in Eq. 5 [58]:

$$(FS_{RL/C}^r)_p = [\sum_{i=1}^n l_i w_i^g, \sum_{i=1}^n m_i w_i^g, \sum_{i=1}^n u_i w_i^g] \quad (3.5)$$

- The fuzzy risk score representing the risk's level of importance was adapted from [55] where the fuzzy scores base on likelihood (FSr RL)_p and fuzzy scores base on likelihood based on consequence (FSr C)_p for a specific project phase (p) or entire project, respectively. The fuzzy technique uses the traditional fuzzy if-then rules to draw inferences about risks, based on the probability of occurrence and consequence. Only ambiguous if-then rules can be created by subject matter specialists who are inevitably arbitrary and unpredictable because each differs in their levels of expertise, experience, and decision-

making capacity. As a result, fuzzy if-then rules have been criticized for failing to address the subjectivity and ambiguity [55].

- The fuzzy risk score determined according to risk likelihood and severity is defined by the following Eqn. (Xu et al. 2010):

$$(FRS_r)_{l,m,u} = \left(\sqrt{(FS_{RL}^r)_p * (FS_C^r)_p} \right)_{l,m,u} \quad (3.6)$$

- Defuzzification is necessary to provide the risk categories ranging from “Very Low” to “Extreme,” calculated as follows:

$$(FRS_r)_{DEFF.} = \frac{(FRS_r)_L + (FRS_r)_M + (FRS_r)_U}{6} \quad (3.7)$$

The defuzzified value obtained is mapped to the equivalent degree of risk for each risk factor as indicated in Table 3.2.

3.3.1.2 Canonical Model

Using the canonical model of multi-causal interactions, two variables must be established to assess risk: prior probabilities and conditional probabilities between a pair of hazards. The causal relationship between a parent risk and its dependent risk is assumed by the model to be independent of other parent risks which is described as “disjunctive interaction.” The canonical model was illustrated by Gingnell [62] and Pearl [63]. The following fundamental Bayes equations are used in this model to calculate the fuzzy probability of the dependent risk:

$$(P(y \cap x_i))_{L.M.U} = (P(x_i))_{L.M.U} \otimes (P_i(y/x_i))_{L.M.U} \quad (3.8)$$

Which will be used to find $(P(x_i))_{L,M, U}$ and $(P_i(y/x_i))_{L,M, U}$ by elicitation of the expert opinion.

The probability of dependent risk can be calculated by [63] :

$$(P(y))_{L.M.U} = (\sum_{i=1}^n P(y \cap x_i))_{L.M.U} \quad (3.9)$$

Finally, given that dependent risk y , the probability of independent risk x_i , $P(x_i|y)$ calculated by [63]:

$$P(x_i|y) = \frac{P(y|x_i) \times P(x_i)}{P(y)} \quad (3.10)$$

3.3.2 FCM Cost Overrun Assessment

The establishment of the causal links between risks is the first and most crucial stage in demonstrating the FCM model's relevance in cost overrun risk assessments. With the aid of expert knowledge, the links can be established using previously verified cause-and-effect connections between the risks.

3.3.2.1 Development of risk networks

However, depending on the type and size of the project, the risks and probability of cost overruns may differ dramatically. For instance, the contracting terms and conditions, number of parties involved, and sophisticated investment and administration systems differ between public investment projects and public-private partnership projects. The present research considered construction projects impacted by COVID-19, where the owner may have self-funded or managed

money pooled from a variety of national or international funding investment organizations. Causal risk networks are created by using expert knowledge, a method often used to create Bayesian belief networks [64]. In this research, the major cost overrun risks caused by COVID-19 were first identified, and then the causal linkages between the risks developed. For example, see Table 3.1 in the previous section, as that study was conducted to highlight the major effects on construction activity caused by COVID-19. The causal linkages between these risks were originally established based on meetings with skilled construction managers, then subsequently validated by holding a focus session with specialists in the construction sector. The focus group consisted of 12 experts: three project owners, one general manager of a contracting company, four project managers, and four site/AE engineers, all with approximately 10 to 25 years of relevant experience.

The focus group discussion began with an explanation of the goal and procedure for creating the risk networks. The experts were then asked to review the causal risk networks, with a specific focus on frequently occurring risks that have a direct or indirect impact on project finance and were most dominant during COVID-19, particularly for projects in the construction phase. The choices were made based on the advice of experts to reduce needless complexity in the networks, while also offering sufficient useful information about cost overrun concerns. Next, the nodes and connections between the nodes were changed per the experts' advice. After several rounds of qualitative meetings with the experts, a few risks were introduced, some causal links restored, and certain risk terminology updated. A list of the modifications made to the risk networks following the focus group talks is provided in Appendix A. The resulting cause-effect relationship networks for the cost overrun risks in the Saudi Arabian construction sector caused by COVID-19 are shown in Figure 3.2.

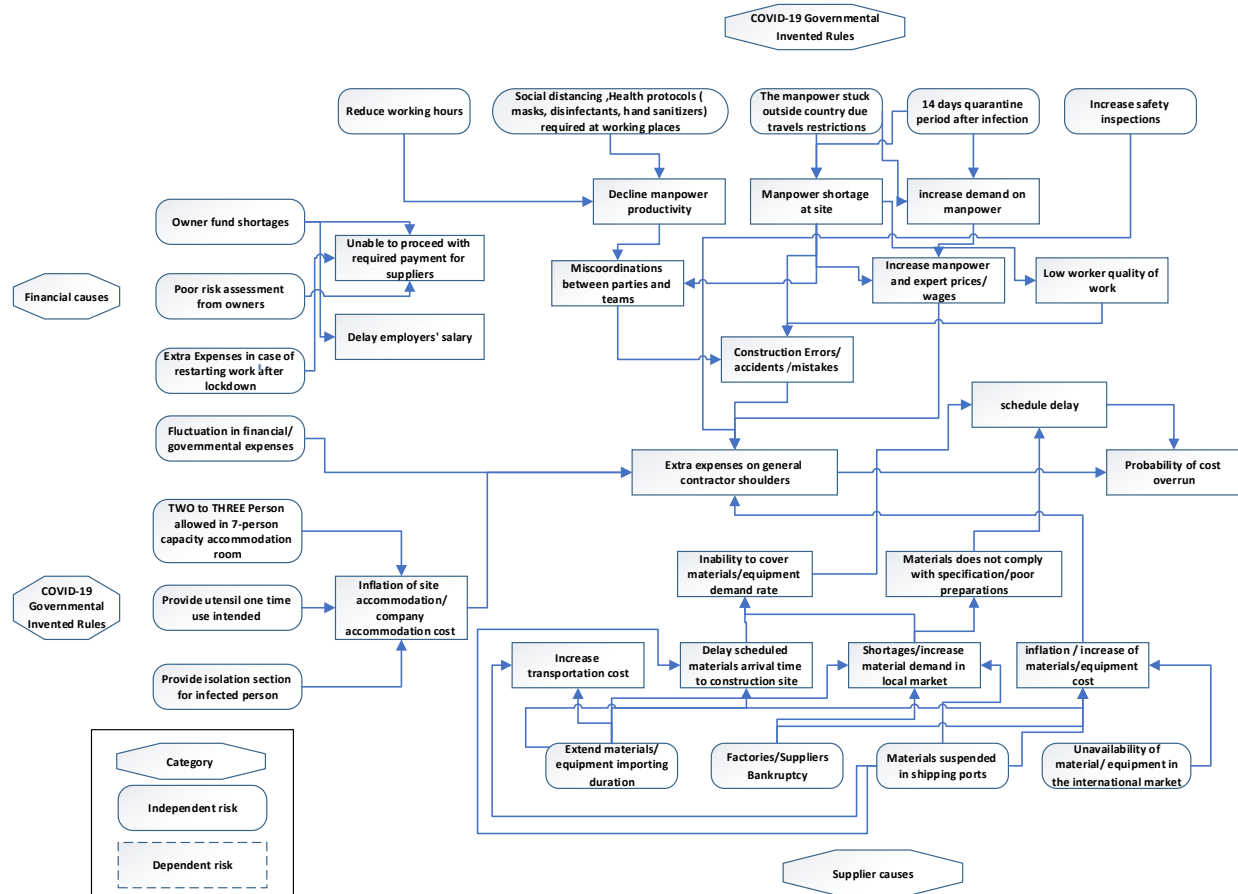


Figure 3.2 Risk propagation networks

3.4 Finding The Probabilities of Input Variables

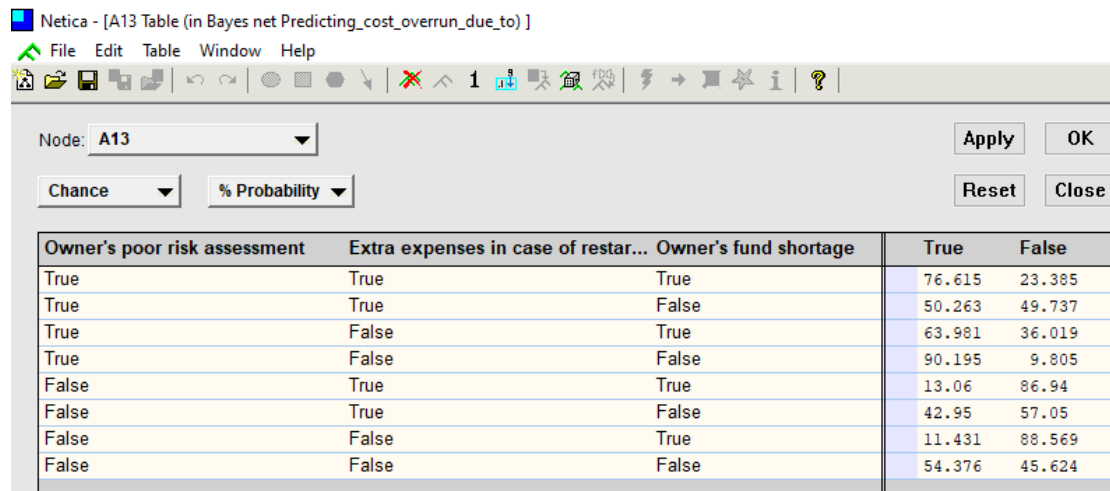
The proposed FCM requires two sets of probabilities for risk assessment: the prior probability of independent risk and conditional probabilities between risks, the latter referring to probabilistic causal relationships between pairs of hazards. It was possible to obtain prior and conditional probabilities from the subject matter experts. A comprehensive questionnaire was created and distributed to experts in the field of construction. The experts were asked to rate the probabilities on a qualitative scale ranging from "Extremely Low" to "Extreme," and then translate the fuzzy probabilities from the survey to the independent risks appendix and causal interconnections

between pairs of risks. Then, conditional probability tables (CPTs) were created using the expert program Netica. Netica uses a "noisy-or" distribution, a popular canonical model, to generate CPTs based on the weights of the independent risks and their connection to the dependent risk[65]. In the noisy-or gate (i.e., disjunctive interaction) kind of canonical model, a true condition of a single risk may cause greater consequences, regardless of the true condition of other risks impacting the dependent risk [66]. Funding shortages, for instance, may have a substantial influence on cost overruns in Figure 3.2, but a simple improvement in the owner's risk assessment might result in a major cost overrun; on the contrary, according to canonical probability theory, if both hazards become real events, only the cost overrun will increase (i.e., the noisy-or gate). Then, to formulate the conditional probability, 12 skilled professionals were consulted; the individuals had experience ranging from 10 to 25 years in construction in Saudi Arabia, including during the COVID-19 epidemic. They responded to the survey questions using the qualitative scale shown in Table 3.2. They assessed the pairwise likelihood function between the risks and prior probabilities, as well as the edited risks (as illustrated in Appendix A. The fuzzy prior probabilities of the independent risks were obtained from a questionnaire survey (Appendix B) of 59 randomly chosen specialists working in various areas of building construction.

3.4.1 Cost Overrun Risk Assessment Findings

The Netica application Netica 604 (<http://www.norsys.com/>) was the first step in developing the canonical model. To initiate the model in Netica, the risk network for the probability of cost overruns for a construction project caused by the emergence of COVID-19 was selected. This model contained 16 independent and 18 dependent risks and 49 different relationships between risks. The expert knowledge elicited was analyzed using the FGDMA, along with the conditional

one-to-one correlations between the risks included in the risk-network model and fuzzy prior probabilities for all independent hazards. As inputs to the model, all independent risk values and conditional risk relationship values were defuzzified. Figure 3.3 shows the program initial program outcome of Conditional Probability Table (CPT) for the cost overrun probability and associated parent risks generated by Noisy-Or.



Netica - [A13 Table (in Bayes net Predicting_cost_overrun_due_to)]

File Edit Table Window Help

Node: A13

Chance % Probability

Apply OK

Reset Close

Owner's poor risk assessment	Extra expenses in case of restar...	Owner's fund shortage	True	False
True	True	True	76.615	23.385
True	True	False	50.263	49.737
True	False	True	63.981	36.019
True	False	False	90.195	9.805
False	True	True	13.06	86.94
False	True	False	42.95	57.05
False	False	True	11.431	88.569
False	False	False	54.376	45.624

Figure 3.3 Conditional Probability Table (CPT) for the cost overrun probability and associated parent risks generated by Noisy-Or

The weighted noisy-or model was used to build CPTs for each risk. In the meantime, taking into consideration the results of previous research, the conditional probabilities were calculated using a 20% leaky noisy-or. The researcher found that while respondents covered 75% to 90% of the major factors evaluating the project's performance and success in terms of time, money, and quality, they were not able to understand the leaky probability [67]. This meant that instead of asking respondents about the leaky probability, a 20% value was assumed. This meant that in addition to the risks mentioned in this study, there was a 20% potential for project cost overruns. The properties were entered into an equation to generate the CPTs in Netica, and each risk's weight used to determine the likelihood of a cost overrun.

In Figure 3.3, a CPT with probabilities for three significant parent risks is displayed. For other dependent risks, equivalent equations were entered into Netica to obtain the CPTs. Figure 3.4 shows the RP diagram results for construction projects using FCM noisy-or with 20% leaky.

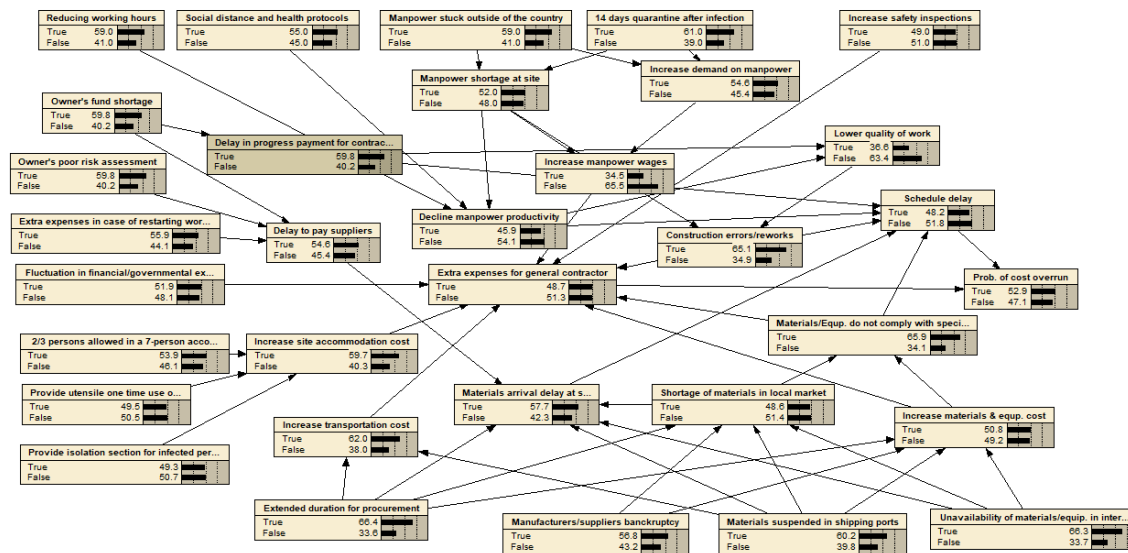


Figure 3.4 Application of FCM to the construction phase (mid).

Figure 3.4 illustrates the model outcome for the risks evaluation model, the results show that the unavailability of material/equipment on the international market and extended materials/equipment importation duration had very high RP values, above 65%. There was a high likelihood, between 55% and 65%, of owner fund shortage, reduced working hours, workers unable to enter the country due to travel restrictions, a 14-day quarantine period after infection or for international arrival, factory/supplier bankruptcy, materials being suspended in shipping ports, and poor risk assessment by owners. All of the former had a high probability of occurrence (above 55% and below 65%). Finally, the probability of overall cost overruns was found at the peak point of 65.8%. Table 3.3 shows the rankings of the independent risks that most affected the construction projects; their sorting depended on the scores extracted from the FCM model. For

example, the unavailability of materials/equipment on the international market and extended materials/equipment importation duration at 66% showed as the top two critical risks affecting construction projects during the outbreak of the COVID-19 pandemic. Construction errors/mistakes/accidents caused by miscoordinations between involved parties and teams at the construction site were the most significant dependent risk, with a 65.5% FCM score.

3.4.2 Model Validation

To assure the suggested knowledge-based model is solid theoretically and practically, a comprehensive validation is required. Fuzzy Bayesian models have frequently been validated using well-known techniques such quantitative benchmarking, severe condition tests, various scenario analyses, and sensitivity testing[53,68]. Benchmarking validation demonstrates how the model outperforms conventional methods in obtaining the desired results while preserving transparency and simplicity in the computations. Due The lack of comparable standard cost overrun risk assessment networks and findings for the impact of implementing COVID-19 prevention strategies on construction projects in the literature prevented this study from conducting a completely quantitative benchmarking validation. Instead, we carried out an axioms-testing-based partial quantitative validation[68,69]. Additionally, sensitivity analysis, additional scenario analysis, and an extreme-condition test were carried out[53,68]. The specifics of the validation are presented in the next subsections.

3.4.2.1 Partial Validation

The suggested FCM's quantitative validation was conducted using the three-axiom-based partial quantitative validation technique[69]. According to the first axiom, "a little rise or reduction in the prior probability of the parent nodes should unquestionably enhance or reduce the posterior probabilities of the child nodes.". To test this axiom, all of the parent nodes' prior probability were raised by 2%, which led to very comparable changes in all of the child nodes' posterior probabilities. For instance, the rearward probability of decline manpower productivity, construction errors/reworks, extra expenses for general contractor and prob. Of cost overrun by 1.75%, 1.37%, 5.47% and 3.54% respectively. The second axiom states that "the overall influence of the probability changes from the set of $m-n$ ($n \in m$) characteristics (sub-evidence) should always be higher than that from the set of x attributes (evidence) on the final conclusion.". Fig 5 demonstrates that an increase in the probability of lower quality of work increases the probability of a cost overrun; an increase in the probabilities of increase manpower wages, materials/equipment do not comply with specifications, and an extended duration for procurement further raises the likelihood of a cost overrun, whereas a further rise in inflation gradually raises the likelihood of a cost overrun.

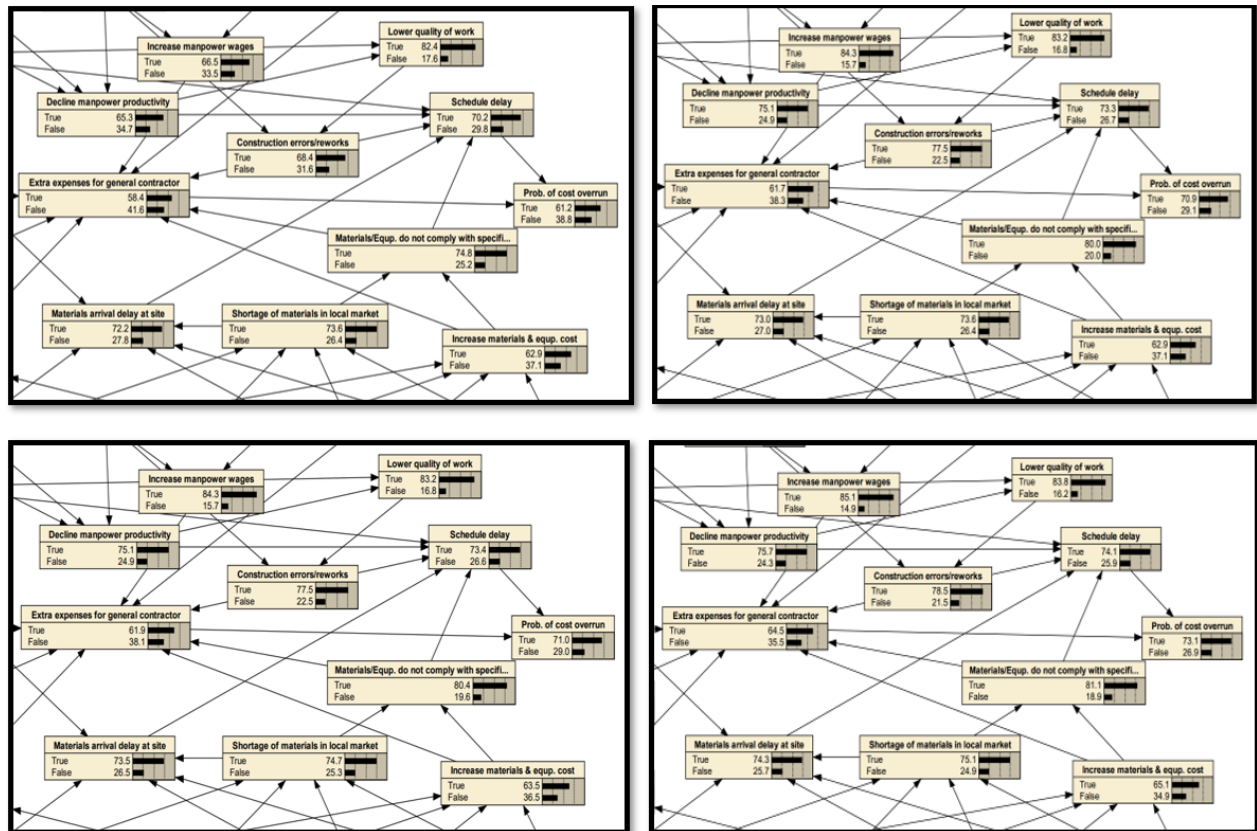


Figure 3.5 Third axiom test for partial validation of the FCM

while the third axiom is stated as follows: "Each parent node shall consistently impact the child node despite variations in its subjective probability distributions.". The outcomes of the scenario analysis, which was mentioned previously, and the findings in Fig. 6 clearly demonstrate that Noisy-OR (0% leaky) with modified CPTs distributions yields a consistent result for the probabilistic evaluation of cost overruns as shown in Figure 3.5. According to the definition of the fuzzy probabilities of linguistic variables (i.e. none to extreme) in Table 3.2, a "consistent outcome" is when the same levels of input probabilities produce similar outputs. For instance, 10 to 30% probabilities of the independent risks produce cost overrun probabilities between 10 and 30%, and so on as illustrated in Figure 3.6 Comparative scenario analysis using different distributions of CPTs in FCM.

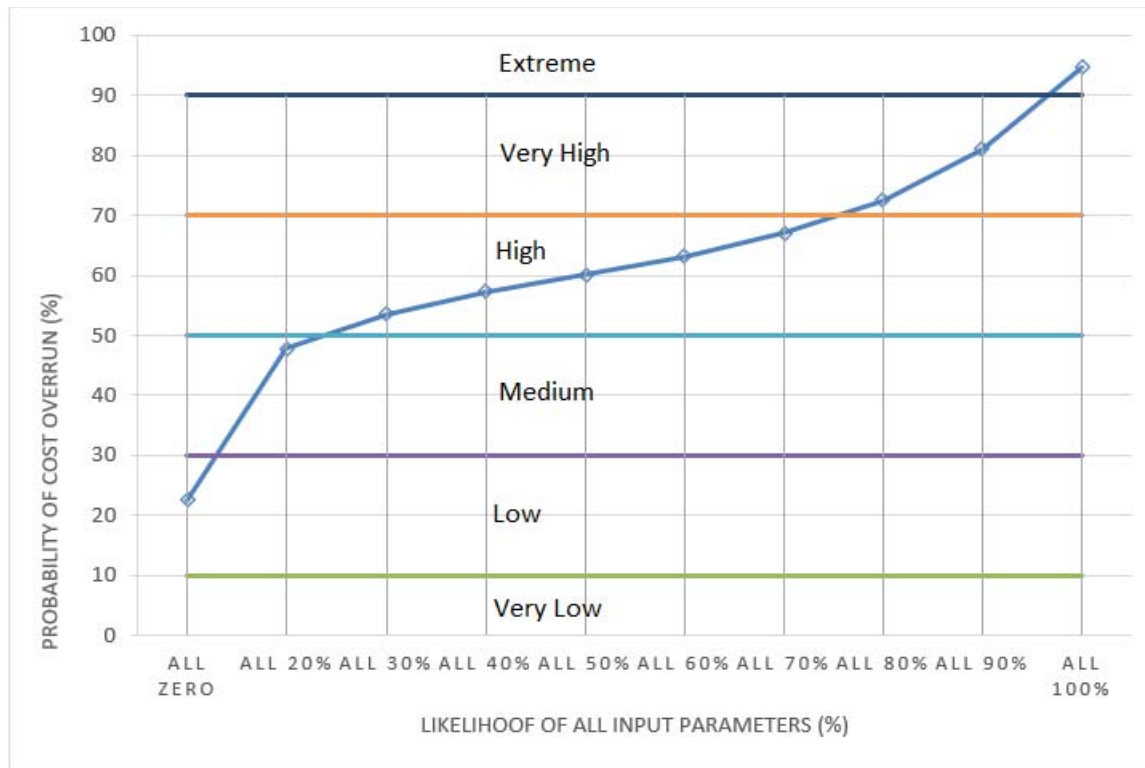


Figure 3.6 Comparative analysis using different distributions of CPTs in FCM

3.4.3 COVID-19 Risk Ranking

For independent risks, the results show that the unavailability of material/equipment on the international market and extended materials/equipment importation duration had very high RP values, above 65%. There was a high likelihood, between 55% and 65%, of owner fund shortage, reduced working hours, workers unable to enter the country due to travel restrictions, a 14-day quarantine period after infection or for international arrival, factory/supplier bankruptcy, materials being suspended in shipping ports, and poor risk assessment by owners.

The results of this research further demonstrate that the primary dependent hazard, reduction in human resource productivity, resulted from reduced working hours, onsite worker shortages due to the 14-day quarantine, inability to proceed with required payments to suppliers, and delays in employee salaries resulting from owner funding shortages. The following factors recommended by the model are listed as follow:

- Inflation/increase in material/equipment costs resulted from an unavailability of materials.
- Shortages/increase in materials demand from extended materials/equipment importation duration.
- Increase in materials demand on the local market from factory/supplier bankruptcy.
- Delay in scheduled materials arrival time from materials being suspended in shipping ports, insufficient quality of submitted work from delays in employees' salaries.
- Extra expenses for general contractors from increases in transportation cost and inflation or increase in materials/equipment costs.
- Inability to cover materials/equipment demand rate from shortages of materials on the market.
- Construction schedule delays from the inability to cover materials/equipment demand rate, project schedule delays from the inability to proceed with required payments for suppliers.
- Construction errors/mistakes/accidents from miscoordination between parties and teams.

All of the formers had a high probability of occurrence (above 55% and below 65%). Finally, the probability of overall cost overruns was found at the peak point of 65.8%. Table 3.3 shows the rankings of the independent risks that most affected the construction projects; their sorting depended on the scores extracted from the FCM model. For example, the unavailability of materials/equipment on the international market and extended materials/equipment importation duration at 66% showed as the top two critical risks affecting construction projects during the outbreak of the COVID-19 pandemic. Construction errors/mistakes/accidents caused by miscoordinations between involved parties and teams at the construction site was the most significant dependent risk, with a 65.5% FCM score (see Table 3.3 and 3.4).

Table 3.3 FCM Ranking of independent risk caused by COVID-19 measures.

Code	INDEPENDENT RISK CAUSED BY COVID19 PRECAUTION MEASURES	SCORE	RANK
Q14	Extend materials/equipment importing duration	0.66	1
Q13	Unavailability of material/ equipment in the international market	0.658	2
Q4	14-days quarantine period after infection	0.609	3
Q16	Materials suspended in shipping ports	0.6	4
Q7	Owner fund shortages	0.596	5
Q3	The manpower stuck outside the country due to travels restrictions	0.592	6
Q1	Reduce working hours	0.588	7
Q15	Factories/Suppliers Bankruptcy	0.566	8
Q9	Extra Expenses in case of restarting work after lockdown	0.558	9
Q2	Social distancing, Health protocols (masks, disinfectants, hand sanitizers) required at working places	0.547	10
Q10	The Impact of Imposed Rule That limiting the capacity of accommodation room to THREE Persons are allowed in 7-persons room)).	0.538	11
Q8	Poor risk assessment from owners	0.534	12
Q6	Fluctuation in financial/governmental expenses	0.519	13
Q11	Provide a one-time use intended tools in company accommodation units	0.495	14
Q12	Provide an isolation section for the infected person	0.493	15
Q5	Increase safety inspections	0.491	16

Table 3.4 FCM Ranking of dependent risk caused by COVID-19 precaution measures.

Code	DEPENDENT RISK CAUSED BY COVID19 PRECAUTION MEASURES	SCORE	RANK
Q65	“The construction schedule delay” influences “The probability of cost overrun”	0.658	1
Q60	“Miscoordinations between parties and teams” influences “The occurrences of construction Errors/mistakes/accidents”	0.655	2
Q51	“Unable to proceed with required payment for suppliers” influence “The project schedule delay”	0.654	3
Q53	“Increase transportation cost” influence “The extra expenses on general contractor shoulders”	0.647	4
Q38	“Factories/Suppliers Bankruptcy” influence “The shortages/increase material demand in the local market”	0.643	5
Q40	“Materials suspended in shipping ports” influence “The delay in scheduled materials arrival time to the construction site”	0.642	6
Q34	“Extend materials/equipment importing duration” influence “The shortages/increase material demand in the local market”	0.64	7
Q55	“Shortages/increase material demand in local market” influence “The Inability to cover materials /equipment demand rate”	0.634	8
Q50	“Delay employees' salary” influence “insufficient quality of submitted work”	0.631	9
Q66	“The extra expenses on general contractor shoulders” influence “The probability of cost overrun”	0.629	10
Q25	“Owner fund shortages” influence “Delay employees' salary”	0.627	11
Q32	“Unavailability of material/ equipment in the international market” influence “The inflation/increase of materials/equipment cost”	0.619	12
Q35	“Extend materials/equipment importing duration” influence “delay scheduled materials arrival time to the construction site”	0.619	13
Q26	“Owner fund shortages” influence “Unable to proceed with required payment for suppliers”	0.615	14
Q41	“Materials suspended in shipping ports” influence “The shortages/increase material demand in local market”	0.615	15
Q57	“Inflation/increase of materials/equipment cost” influence “The extra expenses on general contractor shoulders”	0.614	16
Q63	“Inability to cover materials/equipment demand rate” influences “The construction schedule delay”	0.613	17
Q17	“Reduced working hours” influence “The Manpower productivity”	0.611	18
Q21	“14-days quarantine period after infection” influence “manpower shortage at the site”	0.605	19
Q37	“Factories/Suppliers Bankruptcy” influence “The inflation/increase of materials/equipment cost”	0.604	20

Table 3.4 FCM Ranking of dependent risk caused by COVID-19 precaution measures (continue).

Code	DEPENDENT RISK CAUSED BY COVID19 PRECAUTION MEASURES	SCORE	RANK
Q43	"Decline manpower productivity" influences "insufficient quality of submitted work"	0.599	21
Q39	"Materials suspended in shipping ports" influence "The Increase on transportation cost"	0.598	22
Q54	"Delay scheduled materials arrival time to construction site" influence "The inability to cover materials /equipment demand rate"	0.596	23
Q45	"Manpower shortage at site" influences "The miscoordinations between parties and teams"	0.594	24
Q62	"The occurrences of construction Errors/mistakes /accidents" influence "The extra expenses on general contractor shoulders"	0.59	25
Q33	"Extend materials/equipment importing duration" influence "The inflation/increase of materials/equipment cost"	0.588	26
Q46	"Manpower shortage at site" influences "The occurrence of Construction Errors/mistakes /accidents"	0.586	27
Q59	"Insufficient quality of submitted work" influences "The occurrences of construction Errors/mistakes /accidents"	0.586	28
Q36	"Extend materials/equipment importing duration" influence "The increase on the transportation cost"	0.579	29
Q19	"The manpower stuck outside the country due to travel restrictions" influence "The increase on manpower demand"	0.578	30
Q42	"Materials suspended in shipping ports" influence "The inflation/increase of materials/equipment cost"	0.576	31
Q64	"Materials do not comply with specification/poor preparations" influence "The construction schedule delay"	0.574	32
Q44	"Decline manpower productivity" influences "The miscoordinations between parties and teams"	0.567	33
Q52	"Inflation of site accommodation/company accommodation cost" influences "The extra expenses on general contractor shoulders"	0.567	34
Q29	"TWO to THREE Person allowed in 7-person capacity accommodation room increase the company's accommodation cost"	0.563	35
Q47	"Manpower shortage at site" influences "The increase on manpower and expert prices/wages"	0.563	36
Q22	"14-days quarantine period after infection" influence "The increase on manpower demand"	0.559	37
Q20	"The manpower stuck outside the country due to travel restrictions" influence "manpower shortage at the site"	0.558	38
Q24	"Fluctuation in financial/governmental expenses" influences "The extra expenses on general contractor shoulders"	0.555	39
Q27	"Poor risk assessment from owners" influence "Unable to proceed with required payment for suppliers"	0.549	40

Table 3.4 FCM Ranking of dependent risk caused by COVID-19 precaution measures (continue).

Code	DEPENDENT RISK CAUSED BY COVID19 PRECAUTION MEASURES	SCORE	RANK
Q23	“Increase safety inspections” influence “Extra expenses on general contractor shoulders”	0.547	41
Q61	“Increase manpower and expert prices/wages” influence “The extra expenses on general contractor shoulders”	0.543	42
Q58	“Insufficient quality of submitted work” influences “The extra expenses on general contractor shoulders”	0.536	43
Q48	“Manpower shortage at site” influences “insufficient quality of submitted work”	0.534	44
Q28	“Extra Expenses in case of restarting work after lockdown” influence “Unable to proceed with required payment for suppliers”	0.532	45
Q30	“Advise to use one-time use intended tools” influence “The inflation of site accommodation/company accommodation cost”	0.528	46
Q49	“Increase demand on manpower” influences “insufficient quality of submitted work”	0.524	47
Q18	“Health protocols and Social distancing at workplaces” influence “The Manpower productivity”	0.507	48
Q31	“Provide isolation section for the infected person” influence “The inflation of site accommodation/company accommodation cost”	0.506	49
Q56	“Shortages/increase material demand in local market” influence “Materials does not comply with specification/poor preparations”	0.504	50

3.4.3 Conclusions

Infrastructure-related risks are complex, interconnected, and non-linear. In this study, we created a fuzzy canonical model (FCM) to estimate the risk of cost overruns on construction projects as a result of putting COVID-19 precautionary measures under practice. The created model is unusual in that it combines a FGDMA with the canonical model to solve the difficulty of the risk assessment procedure in substantial, intricate projects. There are certain fundamental problems with the current fuzzy-based expert systems, including fuzzy-AHP, fuzzy-ANP, fuzzy-FMEA, fuzzy-TOPSIS, and fuzzy-BBN, which are covered in literature review 2. For example, fuzzy-AHP cannot manage the causal link between risks at the same phase and the effect of risks at separate phases, and the pair-wise comparison of the AHP technique is time-consuming for a large number of risks engaged in the assessment process. Although the fuzzy-ANP resolves some of these problems, this method still necessitates a significant number of subjective judgment-based pairwise comparisons among the hazards, much like AHP. Even though the fuzzy-FMEA is an appropriate expert system, this method ignores the relative relevance of the risk assessment variables while ignoring the causal links between the hazards.

By combining the modified fuzzy group decision-making technique (FGDMA) with the canonical model, the proposed FCM theoretically addresses these constraints and adds to the body of current knowledge (a modified form of BBN). The FGDMA incorporates the expertise of the experts, data consistency analysis, and a quantitative risk aggregation approach for risk ranking, thereby overcoming the drawbacks of fuzzy logic-based risk assessment systems. The restrictions associated with the current FBBN models are addressed by the canonical model. Given that it requires fewer probability parameters, accurately depicts conditional probability distributions, and

involves less model building work while maintaining the dependability of the results, the canonical model application as the Noisy-Or technique has several important benefits. Although while there are insufficient data to create a conditional probability distribution, a Noisy-Or matches the distribution more accurately than a conditional probability table, which fits the real distribution better[70].

This study first extensively established causal risk-networks for risk created by implementing the COVID-19 preventive measures to evaluate the cost overruns utilising the expertise of specialists working construction projects in order to show the industry the usefulness of this model. Additionally, it elicited the fuzzy probability of the separate risks and evaluated the degree of causality between pairs of risks utilizing the expertise of the domain experts.

Those identified risks and the causal connections between them that were demonstrated in this study can be utilized to determine a realistic, more precise cost contingency amount in early project planning. By creating a strategic risk management strategy in advance, the project managers may leverage these causal links between the risks and their probability degree of significance to assist limit project costs. The model may be used by the contractors to assess risk and calculate the project markup during the bidding process.

3.4.4 Limitation and Future Research

Despite all of efforts to create thorough causal risk-networks for the project throughout the construction phase using professional expertise, the model's application is only possible during the construction phase. The project environment and the decision makers' degree of expertise might affect the causal linkages between the risks, which are not always absolute[71]. In order to meet the needs of the decision-makers and the project's contextual environment, the networks shown

may need to be modified. The risk networks used in this study were developed using the expertise of experts working in project construction field; as a result, the project-specific details and national conditions may have introduced some biases into the networks' formation and the results of the risk assessment that resulted from it. Finally, the focus of this study was restricted to evaluating the risks associated with the implementation of COVID-19 preparation measures in the construction industry.

In this analysis, other external factors that could emerge in the future or alternative sources that might start new risks that influence construction projects—risks that could have a big impact on project cost overruns or project selection—were ignored. These and other feature hazards should be taken into account in further research since they might manifest in the form of future disasters that could affect construction projects. Before deploying the model in that situation, the produced risk-network must be changed appropriately using the expertise of experts.

CHAPTER 4

RISK ASSESSMENT MODEL TO ENHANCE CONSTRUCTION RESILIENCE IN RESPONSE TO COVID-19 PRECAUTIONS MEASURES

Risk management is defined as the process of evaluating the potential risks and hazards present in a particular environment, activity, or situation. It involves identifying potential risks, assessing the likelihood and severity of those risks, and determining the appropriate measures to mitigate or manage those risks.

4.1 Introduction

Risk management is commonly used in various fields such as safety, health, environment, security, finance, and construction to ensure that risks are identified and reduced to acceptable levels and to enhance the level of resilience [72]. While risk management in construction project is the process of identifying, analyzing, and evaluating potential risks or hazards in a construction project success. The risk management involves identifying potential risks, determining the probability of their occurrence and impact, and assessing all risks associated with the project, including factors such as safety concerns, environmental impacts, economic issues, regulatory compliance requirements, and technical challenges [73]. A thorough and comprehensive risk assessment ensures the safety of workers and stakeholders, minimizes financial losses, and ensures that the project meets regulatory and legal requirements. The risk assessment process helps project managers to develop effective risk management strategies that can mitigate or avoid risks and improve the project resilience level, as well as to plan for any potential contingencies that may arise during the course of the project [73,74]. There are several steps that can be taken to use risk

assessment models to improve the resilience of a construction project such as defining potential risks that the construction project may face, which could include natural disasters, equipment failure, accidents, and disruptions to the supply chain. Also, it is important to analyze the likelihood of the risk occurring and the severity of its impact [75]. After that, the identified risk will be prioritized to focus on those that are most likely to occur or have the greatest impact on the construction project. The prioritization process is essential for allocating scarce resources to the project that have the highest level of resilience. Once the risks have been identified and prioritized, mitigation strategies should be developed. Mitigation strategies could include alternatives such as redundancies, backup systems, and contingency plans. Implementing monitoring, and controlling risk mitigation strategies are essential to be applied frequently which result in continuous improvement of the project resilience [76]. It should be an ongoing process that is continuously monitored and improved upon which needs regularly updating risk assessments, identifying new risks, and updating mitigation strategies as necessary. In summary, using risk assessment models is an effective way to improve the resilience of a construction project. Overall, incorporating risk assessment models into construction project planning improves decision-making, enhances communication among team members, and ultimately increases the project's overall productivity and resilience, making it less susceptible to negative outcomes [77]. Evaluating the risks by risk assessment models is a crucial step in enhancing the resilience level of construction projects.

Once the risks are identified, construction project managers can take appropriate measures to enhance the resilience level of the project. These measures may include implementing safety protocols, conducting regular safety inspections, improving emergency response planning, training workers on safety procedures, and ensuring proper maintenance of equipment and infrastructure. Enhancing the resilience level of construction projects helps ensure that they are better prepared

to withstand adverse events and minimize their impact on the project timeline, costs, and reputation. By evaluating and managing risks through effective risk assessment models, construction project managers can create safer, more resilient project sites, which ultimately leads to successful project delivery [78,79].

The first mention of the theory of resilience was introduced in the fields of ecology and natural disasters in the 1970s. The resilience is defined as "a measure of the persistence of systems and their capacity to absorb change and disturbance while maintaining the same linkages between populations or state variables" [80,81]. In other words, resilience is defined as the capacity of a system to absorb disruptions while maintaining its essential function and structure. Resilience comprises of three key features including, the amount of disruption a system can take while remaining in the same state or domain of attraction, the degree to which the system is capable of self-organization, and the ability to build and improve learning and adaptive capacity [3].

In 1990, the theory of resilience was introduced into the field of urban planning and construction [4]. Since that time, scholars around the world have explored the concept of resilience, as well as the best evaluation methods for enhancing disaster resilience in construction industry [4]. As a result, recently numerous organizations focus on how cities should prepare for and recover from disasters. The resilience has become a crucial component among the construction community corresponding with the need to improve construction companies' levels of adaptation, absorbability, resistance, and recovery, trending topics in the construction sector by implementing risk assessment models to enhance the resilience level of construction projects, such research is termed construction project resilience, or more particularly, "project management resilience".

The goal of project management resilience is the development of thorough methods for assessing the situation, as well as responses and activities, ultimately building better preventative and control strategies for future global health. Using previous research on resilience theory, this study identifies and assesses risks associated with the imposed COVID-19 pandemic precaution measures which lead to better manage and mitigate probability of the risks occurrence and impact by developing a risk assessment model. For instance, the COVID-19 outbreak that occurred around the world in early 2020 posed a severe threat to the global population, and many areas still face uncontrolled infection rates. As a result, it is essential to understand the theory of the improvement of construction resilience in this context, by utilizing risk assessment models and strategies for enhancing construction projects level of resilience.

A systematic model was developed to determine all of the factors resulting from COVID-19 that led to construction delays and cost overruns. The defined factors were then sequenced in terms of structural level and significance. The methodology followed in Chapter 3 involved members of construction management organizations operating at different levels. Then, a FCM was developed to obtain a multi-level hierarchical structure consisting of dependent and independent factors. These factors were employed to construct a risk measurement scale of the resilience levels of construction projects.

The research presents a second model to utilize the most critical risk factors defined in the first model to predict the success assessment for a projects' portfolio. The project manager will be able to defines the projects with highest success rate to be prioritized in devoting resources and efforts after the pandemic. The full consistency method is used to predict the project's success rate. This will contribute to efficient implementation of construction activities and better utilization of

project budgeting and construction processes. Particularly, the goal of the present research was to find a solution to the following question:

How can we initiate a risk assessment model that assesses construction project portfolio resilience to minimize the probability of schedule delays and cost overruns associated with COVID-19 precaution measures and increase the potential of controlling construction activities in cases of future hazards?

This section investigates the resilience levels of construction projects in Saudi Arabia. The following objectives were pursued.

- 1) Develop a risk assessment indicator constructed from direct COVID-19 impacts that provide a scale reflecting project resilience behavior. The principle of risk assessment is frequently used to deal with uncertainties and disruptions across a variety of sectors. However, few studies have evaluated the resilience levels of construction projects. Completing a project is a complicated process that involves engineering tasks that necessitate not only a massive utilization of resources, but also the coordination of construction operations. All of these aspects influence the resilience level, which in turn has a substantial impact on the overall project success. The proposed model will enable the project decision-maker to:

- Consider all uncertainties and risks associated with the occurrence of a risk;
- Indirectly influence the future project budgeting and estimation;
- Take into consideration alternative plans and strategies to increase the project resilience level; and
- Take the correct action and make appropriate decisions while continuing the project process after a disaster has occurred.

The primary objective of this study was to provide a resilience evaluation method based on risk assessment model. However, there were certain limitations on this research, which are defined below.

- There is a lack of research and work to facilitate resilience, especially across the various construction stages.
- Prior research has assessed resilience using systemic indicators that are inherently difficult to quantify.

4.2 Overview On Construction Risk Assessment

Risk assessment model aims that construction project managers will be able to successfully minimize the damage caused by and duration of a catastrophe or emergency at a predetermined target level once a specific emergency occurs to improve its level of resiliency [84]. To improve the resilience level in response to hazards such as COVID-19 pandemic, it is mandatory to assess the extent of risks impact on construction projects. This section analyzes the recent literature identifying and illustrating disaster resilience scales either for urban communities or project management. This section also discusses the most recent methods for assigning levels of construction resilience and alternative performance, as well as the implications for project processes. Al-Shamsi (2017) presented a risk assessment model for construction projects in Saudi Arabia. The model aims to help project managers identify, evaluate, and manage risks in order to improve the success rate of construction projects. In response to these risks, the authors propose a risk assessment model that consists of four stages: planning, identification, evaluation, and management. In the planning stage, the project team determines the scope and objectives of the assessment. In the identification stage, the team identifies potential risks using various sources of information such as historical data, stakeholders' feedback, and expert judgment. The identified

risks are then categorized into different types (e.g., technical, financial, environmental) and ranked based on their likelihood and impact. In the evaluation stage, the team assesses the severity of each risk using qualitative or quantitative methods such as probability analysis, sensitivity analysis, or Monte Carlo simulation. Finally, mitigation or contingency plans were proposed to be as a useful guide for project managers and stakeholders in other regions who are interested in improving their risk management practices [85].

M Rahman (2016) examined a risk assessment model for construction projects to minimize potential losses and ensure successful project completion. The resulting model consists of nine key risk categories: design, procurement, construction, environment, health and safety, financial, legal, political, and social risks. Within each category are specific risk factors that were identified as relevant to the bridge project in question. The developed model could be adapted and applied to other construction projects, with adjustments made based on specific contexts and requirements. Using their model, the authors conducted a comprehensive risk analysis of the bridge project as a case study [79].

Resilience was initially defined as the capacity of a system to respond to external disruptions while keeping its fundamental state [86]. Chih (2022) divided into stages the organizational resilience of the construction industry in the presence of COVID-19 disruptions, from the perspective of dynamic capability. The first step was to empirically investigate the scope and severity of the pandemic's effects on construction companies worldwide. Stock prices and daily longitudinal indices obtained for 80 Chinese and US construction companies and stock markets were analyzed using a combined contagion model, crisis severity index, and student tests. The extension of the pandemic's influence across the construction sector and its fluctuating severity levels over time across locations were revealed to follow a pattern consistent with the pandemic's propagation. The

second objective was to compile the best practices used by construction companies in response to previous economic downturns (i.e., strategies to improve the construction resilience level). Finally, the research suggested ways for construction firms to recover quickly from the epidemic and strengthen their resilience in the face of future disruptions. Such methods included always keeping up to date with regulatory requirements and examining market conditions, especially with respect to economic unpredictability [87].

Wang (2022) argued that it was critical to evaluate construction project resilience. Wang (2022) indicated that prior research had quantified resilience using sophisticated and unfavorable systemic variables. The study explored the significance of a building project's resilience and identified the qualities essential for strengthening resilience. The findings revealed easy and effective ways of calculating project resilience, which could help project managers enhance resilience by applying precise tactics to areas that are underperforming [88].

A study conducted in New Zealand in 2019 after several natural disasters found that improving a construction firm's performance resilience not only reduced the negative effects on businesses and improved performance during normal operations, it also helped to build community resilience. As a result of a triangulation analysis method, the researchers selected the top five indicators that were most significant for measuring the construction industry's resilience including leadership, planning methods, internal resources, decision-making, and employee involvement [89].

Ismail (2017) indicated that comprehensive sustainable post-disaster project construction could be achieved by adhering to key indicators reflecting building sustainability in a post-disaster construction environment, and further researched the dynamic interactions of these indicators on socio-ecological systems. The methodology was broken down into three steps. The first stage

consisted of content analysis of linked research sources. The second stage was dedicated to empirical data collected through interviews conducted during case study sessions. Finally, in the third step, the data from the previous stages were used to create a causal loop diagram illustrating the dynamic interrelationships among indicators and variables in a post-disaster rebuilding system. Using sustainable methods in the planning and design processes, the construction industry could increase the resiliency of housing developments to disasters. Specific techniques identified included enforcing the most sustainable construction methods, reducing wastegates, outlining designs reflecting environmental considerations, effectively employing land use planning, using sustainable building materials, and reducing energy, natural resources, and water consumption [90].

Amaratunga (2018) illustrated the gaps in construction professionals' knowledge, limiting their capacity to establish a more disaster-resistant society. Stakeholder interviews were conducted to examine major policies linked to catastrophe resilience and management. As a result, the study offered critical education, policy, practice, and research suggestions. The main recommended practices included professional and ethical standards should include disaster resilience, regulatory structures are essential for the rebuilding of large-scale disasters, and disaster resilience should be recognized by built environment professional groups through accreditation [91].

Xiang (2021) measured the impact of COVID-19 on community disaster resilience, creating an index system by combining 17 components from five categories: economic capital, social capital, demographic characteristics, institutional aspects, and the physical environment. Then, a questionnaire was distributed to obtain data from 12,000 members of Wuhan's important community groupings. The methodology consisted of a multi-level hierarchical structure and an interpretive structural model. The results of the two combined methods showed that the key

elements determining the resilience of communities affected by COVID-19 are income scale, population vulnerability, and the built environment [92].

The above reviewed papers demonstrate the importance of developing comprehensive risk assessment models that take into account various risk factors that are specific to the construction industry. Effective risk assessments can help project managers to identify potential risks, prioritize actions to mitigate risks, and ensure the overall success of a project.

4.3 Research Methodology

The objective of this chapter is to develop a full consistency method (FUCOM) for calculating the relative importance levels of the identified risks.

4.3.1 Full Consistency Method

FUCOM is based on pairwise comparisons of criteria, where only the $n - 1$ comparison in the model is required. The model presumes the application of a straightforward algorithm with the capacity to verify the model by identifying the comparison's deviation from complete consistency. Pamučar et al. (2018) developed the FUCOM approach to calculate the relative importance levels of several criteria. FUCOM outperformed most traditional methods such as the best-worst method (BWM) and analytical hierarchy process (AHP) [93]. The model's consistency is determined by whether the prerequisites for mathematical transitivity are met. FUCOM offers the opportunity to evaluate a model by computing the error size for produced weight vectors and assessing the level of consistency. For the BWM and AHB methods, pairwise comparisons show redundancy which make them less sensitive to judgment errors, while FUCOM resolves this problem.

FUCOM is preferred because it can be used for various measuring scales representing the preferences of experts [94]. Also, FUCOM offers the best weight coefficient values with the least

amount of subjectivity and inconsistent expert preferences impacting the final values of the criteria weights [95]. Moreover, it is possible to obtain the ideal weight coefficients and validate them using the consistency of the outcomes. FUCOM allows for the ideal weight coefficient values to be determined using straightforward mathematical techniques, favoring particular criteria when evaluating phenomena according to the preference of decision-makers which reduces the risks associated with decision-making [95]. The FUCOM model development will be illustrated in the subsequent sections.

4.3.1.1 Obtaining weight coefficients for criteria

The FUCOM process for determining the weight coefficients of criteria is outlined below: Step 1: The parameters in the predetermined list of assessment parameters $C=\{C_1, C_2, \dots, C_N\}$ are ranked according to their significance, beginning with criteria with major weight values and moving sequentially to the lowest criteria weight value.

$$C_{J(1)} > C_{J(2)} > \dots > C_{J(K)} \quad (4.1)$$

where k represents the observed criterion's rank. When two or more criteria have equal weights, the equal sign is used between the criteria in the phrase in place of the ">" symbol.

Step 2: The ranked criteria are compared and comparative precedence is given by:

$$\left(\varphi_{k/(k+1)}\right) = \frac{C_k}{C_{k+1}}, k = 1, 2, \dots, \quad (4.2)$$

where K represents the ranking of the factor and $k/(k+1)$ denotes the importance (i.e., priority) of the $C_{j(k)}$ ranked criterion in relation to the $C_{j(k+1)}$ ranked criterion.

The criteria are evaluated by:

$$\Phi = (\varphi_{1/2}, \varphi_{2/3}, \dots, \varphi_{k/(k+1)}) \quad (4.3)$$

Step 3: The final weight coefficient values $(w_1, w_2, \dots, w_n)^T$, for the evaluation criteria are computed as follows:

The weight coefficients' final values must meet the following two requirements:

- The weight coefficient ratio must correspond to the relative priority of the observable criteria obtained in Step 2.

$$\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)} \quad (4.4)$$

- The weight coefficients' final values must meet the mathematical transitivity requirement, as shown below:

$$\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)} \quad (4.5)$$

$$\varphi_{k/(k+1)} = \frac{w_k}{w_{k+1}} \quad (4.6)$$

$$\varphi_{(k+1)/(k+2)} = \frac{w_{k+1}}{w_{k+2}} \otimes \frac{w_k}{w_{k+1}} \quad (4.7)$$

4.4 Model Development

Based on the findings from the model developed in Chapter 2 and the empirical knowledge gathered from 59 construction experts responding to the survey, the independent impacts of the COVID-19 precautionary measures mandated are outlined and illustrated in Table 4.1.

Table 4.1 FCM risk weigh impact.

Code	Covid-19 Precaution Measures Impacts	Weight Impact %
C1	Increase safety inspections	49.1
C2	14 days quarantine period after infection	60.9
C3	The manpower stuck outside country due travels restrictions	59.2
C4	Social distancing ,Health protocols (masks, disinfectants, hand sanitizers) required at working places	54.7
C5	Reduce working hours	58.8
C6	Fluctuation in financial/governmental expenses	51.9
C7	Owner fund shortages	59.6
C8	Poor risk assessment from owners	53.4
C9	Extra Expenses in case of restarting work after lockdown	55.8
C10	TWO to THREE Person allowed in 7-person capacity accommodation room	53.8
C11	Provide utensil one-time use intended	49.5
C12	Provide isolation section for infected person	49.3
C13	Unavailability of material/ equipment in the international market	65.8
C14	Extend materials/equipment importing duration	66.0
C15	Factories/Suppliers Bankruptcy	56.6
C16	Materials suspended in shipping ports	60.0

The major 16 independent factors were classified as was described in section 3.4.1, with experts indicating the outcomes of the risks emerging since the COVID-19 pandemic. The most critical risk factors defined in the first model are used to predict the success assessment for a projects' portfolio. The independent factors had to be evaluated and measured regarding their impact on the project. This process will serve as a useful indicator tool for construction managers seeking to evaluate and compare several projects, with the goal of proceeding with the project with the highest

probability of success in a disaster occurrence period. The model FUCOM development process began with step 1, ranking the independent risks according to their significance. The result was as follows:

$C_{14} > C_{13} > C_2 > C_{16} > C_7 > C_3 > C_5 > C_{15} > C_9 > C_4 > C_{10} > C_8 > C_6 > C_{11} > C_{12} > C_1$

In step 2, the assessment criteria's comparative priorities were established, and the vectors of those preferences obtained by $\phi_{k/(k+1)} = C_k/C_{k+1}$ as summarized in Table 4.2.

Table 4.2 vectors of those preferences.

Criteria	C14/C13	C13/C2	C2/C16	C16/C7	C7/C3	C3/C5	C5/C15	C15/C9
$\phi_{k/(k+1)}$	1.003	1.080	1.0150	1.00671	1.00676	1.00680	1.039	1.014

Table 4.2 vectors of those preferences (continue).

Criteria	C9/C4	C4/C10	C10/C8	C8/C6	C6/C11	C11/C12	C12/C1
$\phi_{k/(k+1)}$	1.020	1.01673	1.00749	1.029	1.048	1.00406	1.00407

In step 3, the final weight coefficient values for the evaluation criteria were computed. The weight coefficients' final values had to meet the following two requirements:

- The weight coefficients were compared to determine the relative importance levels, as established in equation:

$$W_k/W_{k+1} = \phi_{k/(k+1)}. \quad (4.4)$$

- The final weight coefficient values required to satisfy the evaluation criteria were obtained by: $W_k/W_{k+2} = \phi_{k/(k+1)} \otimes \phi_{(k+1)/(k+2)}$.

$$(4.5)$$

The final model for calculating the final values of the weight coefficients for the assessment criteria was defined as:

$\min x$

$$\left| \frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)} \right| \leq x, \forall j \quad (4.8)$$

$$\left| \frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \right| \leq x, \forall j \quad (4.9)$$

$$\sum_{j=1}^n w_j = 1, \forall j \quad (4.10)$$

$$w_j \geq 0, \forall j \quad (4.11)$$

Where x represents the final weight of a criterion. The model was employed using the Excel Solver program.

4.5 Model Output and Discussion

Table 4.3 shows the obtained weights for independent risk factors which represents the impact of the associated risk on a construction project. The model findings showed that extended materials/equipment importation duration was the most substantial risk, leading to project cost overruns of 7.3%. Conversely, increased safety inspections factors were reported the lowest risk for a construction project accounting 5.4% project cost overruns.

Table 4.3 Model output factors

Rank	Risks Caused by COVID-19	CODE	Model Risk Weight %
1	Extend materials/equipment importing duration	C14	7.298
2	Unavailability of material/equipment in the international market	C13	7.276
3	14 days quarantine period after infection	C2	6.734
4	Materials suspended in shipping ports	C16	6.634
5	Owner fund shortages	C7	6.590
6	The manpower stuck outside country due travels restrictions	C3	6.546
7	Reduce working hours	C5	6.502
8	Factories/Suppliers Bankruptcy	C15	6.258
9	Extra Expenses in case of restarting work after lockdown	C9	6.170
10	Social distancing, Health protocols (masks, disinfectants, hand sanitizers) required at working places	C4	6.048
11	TWO to THREE Person allowed in 7-person capacity accommodation room	C10	5.949
12	Poor risk assessment from owners	C8	5.904
13	Fluctuation in financial/governmental expenses	C6	5.739
14	Provide utensil one time use intended	C11	5.473
15	Provide isolation section for infected person	C12	5.451
16	Increase safety inspections	C1	5.429

The model indicated the percentage of impact weight for each risk resulting from the COVID-19 precaution measures. To enhance a project's disaster resilience level, such risks must be mitigated and the consequent probability of cost overruns for the project will be reduced. Furthermore, model outcomes can be applied as indicators when comparing portfolio projects sharing the same construction entity and management organization.

4.6 Case Study and Model Testing

The final weight coefficient values derived from the FUCOM model were integrated in survey form to be filled by each project construction managers and decision makers as shown in APPENDEX D to assess and choose the most successful project in case of disasters were to occur.

For Case Study 1, an evaluation was conducted of three hospitals' curtain wall and cladding jobs, which were assigned to the same spatialized subcontractor. The three projects share common essential characteristics that the model applied. All three hospitals were located in the Eastern Province of Saudi Arabia. The materials were manufactured and installed by the same specialized subcontractor specializing in the aluminum and steel fields. The assigned work for the cladding and curtain walls covered more than 80% of the building envelope's finishing.

The scope of the cladding and curtain walls in the Al-Ahsa hospital covered an area of 14,958 m², while the hospital in Al-Khobar involved an area of 31,235 m², and 15,286 m² was the area of the job for the Al-Dammam hospital. Table 4.4 illustrates the assigned job areas for each project.

Table 4.4 Model (2) hospitals input location and characteristics

	Curtain Walls	Cladding	Windows/Doors	Skylights	Louvers	Total Area m ²
Al Ahsa Hospital	9,753	-	3,606	1,231	367	14,958
Khobar Hospital	13,044	12,716	7,245	230	-	31,235
AlDammam Hospital	13,495	-	960	-	831	15,286

One of the major characteristics of these jobs was that the manufacturing and installation work began at the time of the emergence and implementation of precaution measures for COVID-19. The manufacturing and installation work experienced a severe crisis as a result of the normalization of precautionary and preventive measures to control COVID-19, delaying the completion of scheduled activities and resulting in financial problems for all the three projects. Discussion meetings were held with the project manager and resident site engineer to explore how much the dangers posed by the spread of COVID-19 impacted their projects. The survey form in APPENDIX D shows the evaluation of each risk and offers a brief description of the impact level on the project. The practicality of the proposed model was evaluated on two additional commercial buildings. The first building was located in Al-Khobar City consisted of four floors and a basement. The curtain wall scope, with an area of 1,331 m², was handled by a specialized curtain wall company who manufactured the materials and executed the work at the site. Table 4.5 shows a brief breakdown of the work assigned.

Table 4.5 Commercial building input location and characteristics

	Curtain Walls	Cladding	Windows/Doors	Total Area in m ²
Al-Khobar Commercial Building	1,312	-	18.6	1,331
Al-Dammam Commercial Tower	1,574	130	416	2,120

The projects began in 2018, before the emergence of COVID-19 pandemic. The first project experienced a serious delay due to COVID-19 because of issues with importing materials from Germany to Saudi Arabia. The materials were mired in ports because of the implementation of COVID-19 precautions measures. The second commercial tower located in the city of Dammam consisted of nine floors. The area of curtain wall is 2,120 m² was handled by the same subcontractor who carried out the commercial building in Al -Khobar. A risk assessment consultant agency hired by the owner decided to use the Italian curtain wall system, which was available from a local supplier in Saudi Arabia in 2019; this allowed for the avoidance of materials importation and transportation risks. Table 4.6 shows the survey results form that evaluate the project success rate by evaluation the severity impact of each risk on the project. In order to get the accurate result all parties involved in each project like owner, consultant, contractors and engineers should fill the survey.

Table 4.6 Evaluating projects success rate results.

Risks Caused by COVID-19	CODE	HOSPITALS PROJECTS						COMMERCIAL PROJECTS			
		Alahsa Hospital		Alkhobar Hospital		Aldammam Hospital		Alkhobar Commercial Center		Aldammam Commercial Tower	
Extend materials/equipment importing duration	C14	1	7.298	0.75	5.473	0	0.000	1	7.298	0	0.000
Unavailability of material/equipment in the international market	C13	0.5	3.638	0.75	5.457	0	0.000	0.5	3.638	0	0.000
14 days quarantine period after infection	C2	0.75	5.050	0.5	3.367	0.5	3.367	1	6.734	1	6.734
Materials suspended in shipping ports	C16	1	6.634	0.25	1.659	1	6.634	1	6.634	0	0.000
Owner fund shortages	C7	1	6.590	0.5	3.295	0.5	3.295	0	0.000	0.5	3.295
The manpower stuck outside country due travels restrictions	C3	0.75	4.909	1	6.546	0.75	4.909	0.5	3.273	0.5	3.273
Reduce working hours	C5	0.5	3.251	0.75	4.876	0.25	1.625	0.5	3.251	0.5	3.251
Factories/Suppliers Bankruptcy	C15	1	6.258	1	6.258	0	0.000	0.25	1.565	0	0.000
Extra Expenses in case of restarting work after lockdown	C9	1	6.170	0.5	3.085	0.25	1.542	0.5	3.085	0.5	3.085
Social distancing, Health protocols (masks, disinfectants, hand sanitizers) required at working places	C4	0.25	1.512	0.25	1.512	0.25	1.512	0.75	4.536	0.75	4.536
TWO to THREE Person allowed in 7-person capacity accommodation room	C10	0.5	2.974	0	0.000	1	5.949	0.5	2.974	0.75	4.462
Poor risk assessment from owners	C8	1	5.904	1	5.904	0.25	1.476	1	5.904	0.75	4.428

Fluctuation in financial/governmental expenses	C6	0	0.000	0	0.000	0.5	2.869	0	0.000	0.75	4.304
Provide utensil one time use intended	C11	0.25	1.368	0	0.000	0	0.000	0	0.000	0.25	1.368
Provide isolation section for infected person	C12	0	0.000	0	0.000	1	5.451	0	0.000	0	0.000
Increase safety inspections	C1	0.5	2.715	1	5.429	1	5.429	0.5	2.715	1	5.429
			64.272		52.861		44.060		51.606		44.165

A project score of 60% or above meant that the project was severely affected by the crisis and was unable to be completed as planned, unless outsourcing could improve the situation. A project score between 50% and 60% reflected that the project was affected by the crisis, but still able to reach the planned goals. There may have been delays, but not to the extent faced by projects reaching a score of 60% or more.

A score of less than 50% reflected projects that were able to overcome the crisis with only minor or inconsequential harm, successfully carrying out their scheduled tasks. Testing of the three hospital projects resulted in the weights summarized in Table 4.7. The Alahsa hospital project exceeded the 60% level. The impact of implementing COVID-19 precautions was between 50% and 60% for the other two projects, reflecting that there were delays, but they were able to sustain their work despite the disaster. Importantly, the model reflected that the Al Dammam hospital project was able to survive the disaster and meet the completion date, receiving a score of 44%.

Table 4.7 Success score of portfolio projects

HOSPITALS PROJECTS			COMMERCIAL PROJECTS	
Al Ahsa Hospital	Al Khobar Hospital	Al Dammam Hospital	Al Khobar Commercial Building	Al Dammam Commercial Tower
64.3%	52.9%	44.1%	51.6%	44.2%

For the two commercial buildings, the model indicated that the project in Al Dammam had a better success score than the other commercial building located in Al Khobar, with a 7.2% difference between the two projects.

4.7 Conclusion and Recommendations

This study developed a risk-based model to predict the success assessment of project portfolio that can be used to reflect a construction project's responsiveness to external disruptions while returning to its initial state. The results of the model consistently indicate that management methods and assessment tools are required to evaluate the resilience of organizations in the construction industry. Consequently, this study utilized a total sequential method to highlight the most crucial indicators that can aid in developing a framework or guideline to improve the success of construction projects during pandemics. A proposed framework is created and then validated in a follow-up interview with a sample of the same construction practitioners. Then the framework was validated by evaluating several construction projects and conducted it with real life statues of the project. Thus, the model outcome aims could be used to assess a construction project's responsiveness to external disruptions taking into consideration the spread of a disaster and to compare a portfolio of construction projects under the same category of construction to determine which has the greatest success level.

CHAPTER 5

THESIS CONCLUSION

This research concentrated on identifying and understanding the most significant risks associated with the implementation of preventative measures imposed by governments to stop the spread of COVID-19, which in turn caused construction projects to either schedule delay and/or cost overrun. Firstly, a fuzzy canonical model was utilized to identify the project's schedule delay and/or cost overrun. The model's foundation is a synthesis of all the elements discussed in academic studies published in international publications with a focus on the construction industry. These elements were then supported by in-depth research on construction projects. The result of the fuzzy canonical model highlighted the most significant variables that significantly impacted the performance of construction projects. The variables were evaluated and ranked along with the percentage of time that each variable's influence lasted on the development of construction activities.

The outcomes of the first model were then used as inputs for the second model to assess project's responsiveness to external disruptions resulted from covid-19 precautions measures. The established tool aids project managers in making decisions and measuring a project's ability to withstand any type of disaster that may happen in the future while considering updating the factors. The factors identified in this study might alter, vanish, or new variables could emerge. Nevertheless, the methodology used in this study involved limiting and researching all of the risks related to the COVID-19 on the Middle Eastern construction industry, in particular in the Kingdom of Saudi Arabia. The model practicality was validated with in-depth field experiments. In order to verify the findings, the model was implemented to a variety of construction sites, including

hospitals and commercial buildings under construction. After the study's implementation was complete for six months, the model's efficacy was obvious where some project was expected to declare cost overrun then after a certain time it happened as expected. For future research, this study can be enhanced to be used to improve the planning and design of urban infrastructure and buildings. The findings are beneficial for informing future decision-making and the long-term sustainable management of the COVID-19 threats.

By developing this model addressing a crucial aspect of the pandemic's impact on the construction industry and provide a comprehensive framework for assessing the effectiveness of various COVID-19 precautionary measures and their implications for construction projects. This model will be immensely helpful for future research in several ways. Firstly, it will serve as a benchmark for evaluating the success of different precautionary measures implemented during the pandemic. Researchers can use the model as a reference to compare and analyze the outcomes of their own studies. This will facilitate a deeper understanding of the effectiveness of specific precautions and contribute to the development of best practices in the industry. Moreover, the final outcomes will be instrumental in assessing risk and uncertainty in construction projects. The COVID-19 pandemic has introduced unprecedented challenges, and this research will provide a systematic approach to evaluating these risks.

By incorporating factors such as project timelines, resource allocation, and potential disruptions, Finally the results will enable researchers to quantify the impact of COVID-19 precautions on project outcomes. This will aid in decision-making, risk management, and contingency planning, ensuring that construction projects can adapt to uncertain circumstances. The main goal for this research is to have practical implications for the construction industry. Contractors, project managers, and stakeholders can utilize the model to evaluate the cost-effectiveness of

implementing various COVID-19 precautions. This will help in making informed decisions about resource allocation, project scheduling, and risk mitigation strategies and contribute to enhancing safety protocols and ensuring the well-being of construction workers, which is of utmost importance during these challenging times.

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APPENDIX

Appendix A

Illustrate the discussion's focus group feedback summary: Node or link additions or deletions, modifications in the wording used to describe risks.

Category	Node			Terminology Changed	Shifted to Other Phase	Link		Description
	Node Name	Added	Removed			Added	Removed	
COVI-19 Governmental invented rules	limited allowed manpower at the site with health restrictions	X		social distancing and Health protocols		X		As per expert opinion for a better risk layout make it general
	weakness in negotiation with laborers for wages		X				X	Useless to be included it as a separate risk because its already mentioned indirectly in another node
	social distancing influence manpower shortages at site					X	X	the impact of social distancing on the decline the productivity is more practical
	monitor cost irrigation		X					Not significant and rarely have impact
	inflation of site accommodation cost		X		X	X	X	shifted to the COVID-19 accommodation rules category
	Health protocols		X	Social distancing, Health protocols (masks, disinfectants, hand sanitizers) required at working places		X	X	merge the health protocols node with social distancing as they belong to health restrictions by government
	decrease safety care influence the manpower productivity						X	as the expert recommended to be deleted
	decline the safety care	X		Increase safety inspections required				according to experts' opinions to highlight the extra safety restrictions added
	the expert wages increased from Decline manpower productivity						X	the decline in productivity resulted from other risks not connected to expert availability
	low product quality leads to an increase in the change orders						X	No related to the impact of COVID-19 pandemic
COVID-19 Accommodation rules	Inflation of site accommodation/company accommodation cost					X		resulted from three independent invented COVID-19 precautions measures for accommodation
Category	Node			Terminology Changed	Shifted to Other Phase	Link		Description
	Node Name	Added	Removed			Added	Removed	

Financial causes	Unable to proceed with required payment for suppliers					X	X	the impact on delay schedule more significantly than extra expenses on contractors
	Fluctuation in financial/governmental expenses					X	X	no connection with the inability to proceed with the required payment while it only added extra expenses on contractors' expenses
	Extra expenses on general contractor's shoulders lead to change orders						X	rarely happened
	delays manpower salaries					X	X	as expert opinion that it may result in low quality of submitted work while it doesn't have a relation with manpower shortages
Supplier causes	Change orders		X				X	the risk is removed because it has no relation to COVID19 separation
	no materials available at market			Unavailability of material/ equipment in the international market		X	X	the expert said that it impacted directly the inflation/increase of materials/equipment cost and remove the relation with delayed scheduled materials arrival nor extending the transportation costs
	Unavailability of material/ equipment in the international market	X				X	X	two experts with 25 or above years of experience suggest that it impacts more on the inflation/increase of materials/equipment cost while the shortages resulted from other risks
	Factories/Suppliers Bankruptcy	X					X	This important risk added by expert recommendation then suggests removing the connection with transportation fluctuation cost because it's not unrelated
	Increase transportation cost	X				X		Increase transportation cost as result from Extending materials/equipment importing duration

Appendix B

Survey questions using the qualitative scale

Please evaluate the frequency/severity impact level of the following risks that affecting the construction projects' schedule and cost performance caused by implementing COVID-19 precaution measures.

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#	Independent Risk Caused By COVID-19 Precaution Measures.	Levels Of Significance
1	Reduce working hours	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
2	Social distancing Rules Health protocols (masks, disinfectants, hand sanitizers) required at working places	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
3	The manpower stuck outside the country due to travels restrictions	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
4	14-days quarantine period after infection	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
5	Increase safety inspections	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
6	Fluctuation in financial/governmental expenses	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
7	Owner fund shortages	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
8	Poor risk assessment from owners	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
9	Extra Expenses in case of restarting work after lockdown	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
10	TWO to THREE Persons are allowed in the 7-person capacity accommodation room	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
11	Provide utensil one-time use intended	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
12	Provide an isolation section for the infected person	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
13	Unavailability of material/ equipment in the international market	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
14	Extend materials/equipment importing duration	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
15	Factories/Suppliers Bankruptcy	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
16	Materials suspended in shipping ports	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6

Please evaluate the severity impact of the risks affecting the dependent factors that influencing construction projects' schedule and cost performance due to implementing COVID-19 precaution measures.

Ymj {fz fytstklkj fhm fhyt wjfxji tsz mj xj} 2utry xhfqj | mjwj %
6B% [jw-Qt | B/BQt | BBR jirzr BBR mrlm fsi % B% [jw-Mrlm B; B% } wjr j

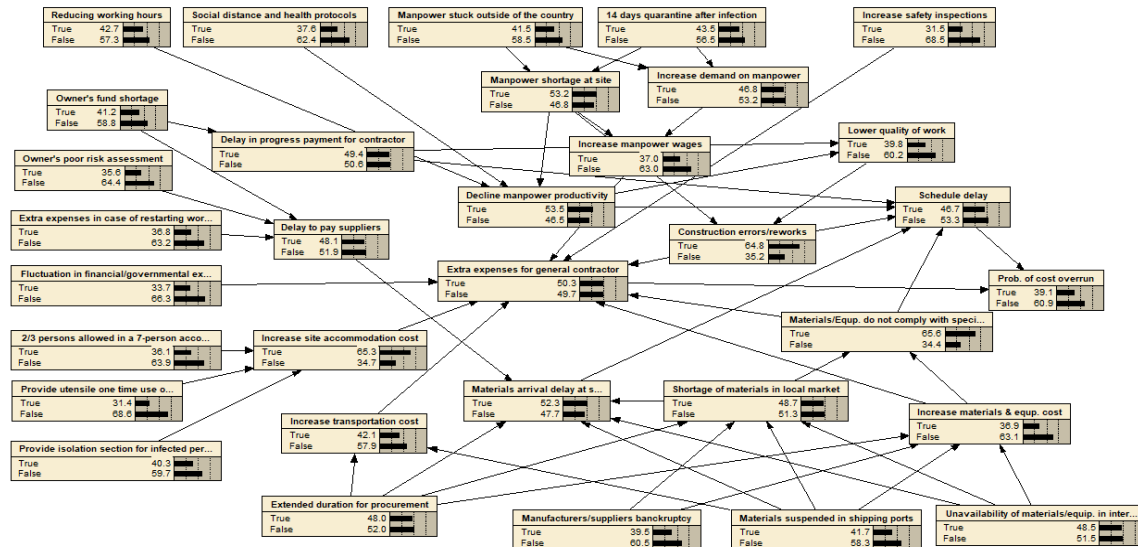
#	dependent risk caused by COVID-19 precaution measures.	Levels Of Significance
1	“Reduced working hours” influence “Manpower productivity”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
2	“Health protocols and Social distancing at workplaces” influence “manpower shortage at the site”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
3	“The manpower stuck outside the country due to travel restrictions” influence “increase demand on manpower”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
4	“The manpower stuck outside the country due to travel restrictions” influence “manpower shortage at the site”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
5	“14-days quarantine period after infection” influence “manpower shortage at the site”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
6	“14-days quarantine period after infection” influence “increase demand on manpower”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
7	“Increase safety inspections” influence “Extra expenses on general contractor shoulders”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
8	“Fluctuation in financial/governmental expenses” influences “Extra expenses on general contractor shoulders”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
9	“Owner fund shortages” influence “Delay employers' salary”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
10	“Owner fund shortages” influence “Unable to proceed with required payment for suppliers”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
11	“Poor risk assessment from owners” influence “Unable to proceed with required payment for suppliers”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
12	“Extra Expenses in case of restarting work after lockdown” influence “Unable to proceed with required payment for suppliers”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
13	“TWO to THREE Person allowed in 7-person capacity accommodation room” influence “Inflation of site accommodation/company accommodation cost”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
14	“Provide utensil one-time use intended” influence “Inflation of site accommodation/company accommodation cost”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
15	“Provide isolation section for the infected person” influence “Inflation of site accommodation/company accommodation cost”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
16	“Unavailability of material/ equipment in the international market” influence “inflation/increase of materials/equipment cost”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
17	“Extend materials/equipment importing duration” influence “inflation/increase of materials/equipment cost”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6

18	“Extend materials/equipment importing duration” influence “Shortages/increase material demand in the local market”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
19	“Extend materials/equipment importing duration” influence “Delay scheduled materials arrival time to the construction site”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
20	“Extend materials/equipment importing duration” influence “Increase transportation cost”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
21	“Factories/Suppliers Bankruptcy” influence “inflation/increase of materials/equipment cost”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
22	“Factories/Suppliers Bankruptcy” influence “Shortages/increase material demand in the local market”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
23	“Materials suspended in shipping ports” influence “Increase transportation cost”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
24	“Materials suspended in shipping ports” influence “Delay scheduled materials arrival time to the construction site”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
25	“Materials suspended in shipping ports” influence “Shortages/increase material demand in the local market”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
26	“Materials suspended in shipping ports” influence “inflation/increase of materials/equipment cost”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
27	“Decline manpower productivity” influences “Low worker quality of work”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
28	“Decline manpower productivity” influences “Miscoordinations between parties and teams”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
29	“Manpower shortage at site” influences “Miscoordinations between parties and teams”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
30	“Manpower shortage at site” influences “The occurrence of Construction Errors/mistakes /accidents”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
31	“Manpower shortage at site” influences “Increase manpower and expert prices/wages”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
32	“Manpower shortage at site” influences “Low worker quality of work”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
33	“Increase demand on manpower” influences “Low worker quality of work”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
34	“Delay employers' salary” influence “Low worker quality of work”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
35	“Unable to proceed with required payment for suppliers” influence “schedule delay”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
36	“Inflation of site accommodation/company accommodation cost” influences “Extra expenses on general contractor shoulders”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
37	“Increase transportation cost” influence “Extra expenses on general contractor shoulders”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
38	“Delay scheduled materials arrival time to construction site” influence “Inability to cover materials/equipment demand rate”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6

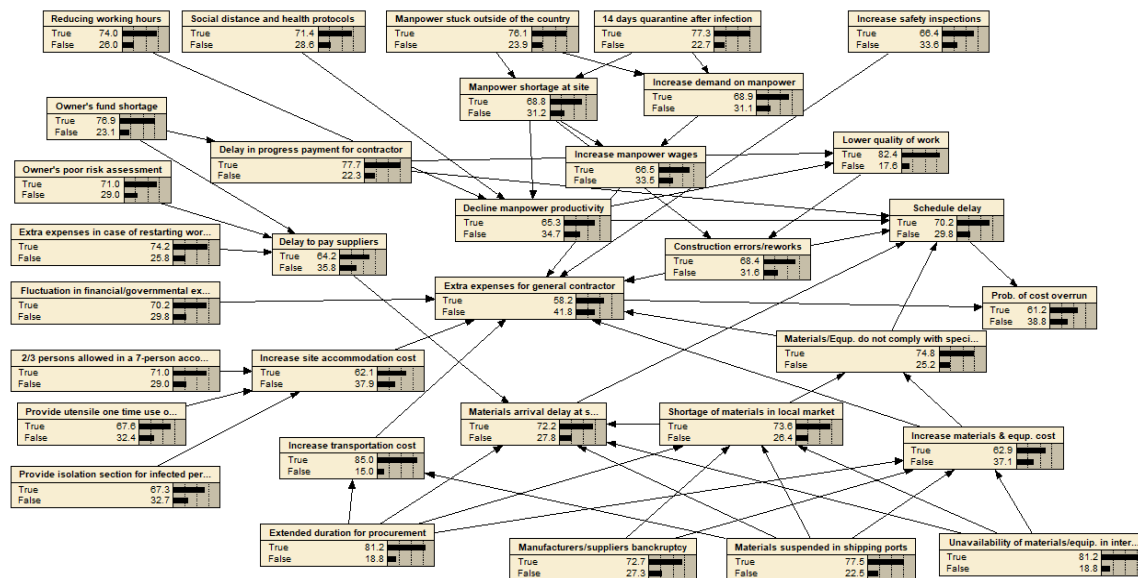
39	“Shortages/increase material demand in local market” influence “Inability to cover materials/equipment demand rate”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
40	“Shortages/increase material demand in local market” influence “Materials does not comply with specification/poor preparations”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
41	“inflation/increase of materials/equipment cost” influence “Extra expenses on general contractor shoulders”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
42	“Low worker quality of work” influences “Extra expenses on general contractor shoulders”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
43	“Low worker quality of work” influences “Construction Errors/mistakes /accidents”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
44	“Miscoordinations between parties and teams” influences “The occurrences of Construction Errors/mistakes/accidents”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
45	“Increase manpower and expert prices/wages” influence “Extra expenses on general contractor shoulders”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
46	“Construction Errors/mistakes /accidents” influence “Extra expenses on general contractor shoulders”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
47	“Inability to cover materials/equipment demand rate” influences “schedule delay”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
48	“Materials do not comply with specification/poor preparations” influence “schedule delay”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
49	“Schedule delay” influences “Probability of cost overrun”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6
50	“Extra expenses on general contractor shoulders” influence “Probability of cost overrun”	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5; ☐ 6

Appendix C

Model 1 Fuzzy canonical model outcomes graphs



Low



Heigh

Appendix D

Model 2 the full consistency method survey form

Rank	Risks Caused by COVID-19	CODE	Model Risk Weight %	Risk Impact on The Project					Risk Impact Weight
				No Effect	Low Moderate	Moderate	Very Severe	Immense	
1	Extend materials/equipment importing duration	C14	7.298						0
2	Unavailability of material/ equipment in the international market	C13	7.276						0
3	14 days quarantine period after infection	C2	6.734						0
4	Materials suspended in shipping ports	C16	6.634						0
5	Owner fund shortages	C7	6.59						0
6	The manpower stuck outside country due travels restrictions	C3	6.546						0
7	Reduce working hours	C5	6.502						0
8	Factories/Suppliers Bankruptcy	C15	6.258						0
9	Extra Expenses in case of restarting work after lockdown	C9	6.17						0
10	Social distancing, Health protocols (masks, disinfectants, hand sanitizers) required at working places	C4	6.048						0

11	TWO to THREE Person allowed in 7-person capacity accommodation room	C10	5.949						0
12	Poor risk assessment from owners	C8	5.904						0
13	Fluctuation in financial/governmental expenses	C6	5.739						0
14	Provide utensil one time use intended	C11	5.473						0
15	Provide isolation section for infected person	C12	5.451						0
16	Increase safety inspections	C1	5.429						0
Total =			100	Cost Overrun Probability =					0